2014 SUMMIT SEEDS & BREEDS FOR 21ST CENTURY AGRICULTURE

rafi

Meeting the Challenges of Food Security

Proceedings of the 2014 Summit on Seeds and Breeds for 21st Century Agriculture

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Edited by Bill Tracy and Michael Sligh

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Foreword

We Plant The Seed
By Ron Rosmann 2014

We plant the seed but the harvest is not ours,

A speck of soil in our eyes, in our lives, in our time spent on the soil. We plant the seed.

We weep for the soil, so to the soil our speck returns, our bodies return, all bodies return,

We do not save our soil, so to the river our speck of soil goes, to the ocean where it weeps for us.

Sustenance for a future harvest that is not our own, we plant the seed.

We plant seeds so we might live, so others might live,

Who no longer stand on the soil, standing instead on cement,

The hardened earth that will be ground up one day returning back to soil,

We plant the seed.

The speck of soil in my eye sees the small Honduran farmer riding his small pony

Up the mountain to tend his soil, his seeds.

Seeds that carry the memory of tens' of thousands of years,

How long will they be his seeds, his brother and sister farmers' seeds?

The public seeds? We plant the seeds. We must save our seeds.

Who can really own the soil or the seed? Do we own the sun? Do we own our own name?

I see a hollowed out scarecrow watching over a hollowed out field,

Grown from seed for a harvest that is not ours to save.

We plant the seeds. We must save our seeds.

To be in communion, we strive to be, with the soil, with the seed,

With the art, with the science,

We must all become farmers in our way.

We plant the seeds. We save our seeds.

PROCEEDINGS:

2014 Summit on Seeds an Breeds for 21st Century Agriculture

The Rural Advancement Foundation International, (RAFI) is dedicated to community, equity and diversity in agriculture. While focusing on North Carolina and the southeastern United States, we also work nationally and internationally. RAFI is playing a leadership role in responding to major agricultural trends and creating a movement among farm, environmental and consumer groups to:

Promote sustainable agriculture

Strengthen family farms and rural communities

Protect the diversity of plants, animals and people

Ensure responsible use of new technologies

The 2014 Summit on Seeds and Breeds for 21st Century Agriculture provided an open forum for the discussion of issues related to public plant and animal breeding. The views presented and positions taken by individual participants and presenters are their own and do not necessarily reflect the views of RAFI.

Recommended cataloguing: Summit on Seeds and Breeds for 21st Century Agriculture (2014: Washington, D.C.) Summit on Seeds and Breeds for 21st Century Agriculture

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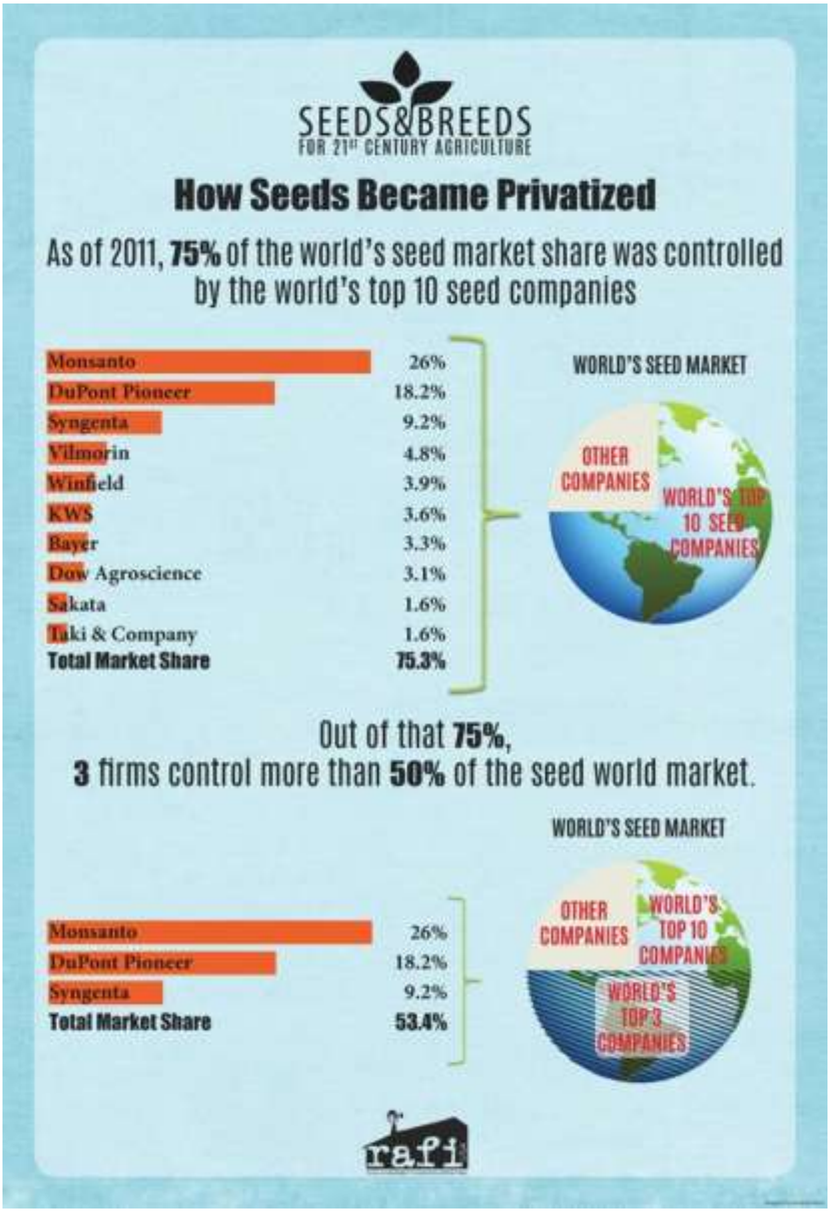

2014 Summit Planning Committee:

Michael Sligh, Rural Advancement Foundation International -USA

Dr. William Tracy, University Wisconsin-Madison

Dr. Jim Myers, Oregon State University

Dr. Margaret Smith, Cornell University

Dr. Julie Dawson, University Wisconsin-Madison

Kristina Hubbard, Organic Seed Alliance

Preface

A BRIEF HISTORY: SEEDS & BREEDS FOR 21st CENTURY AGRICULTURE

Public cultivars developed through classical breeding techniques are extremely successful and powerful public assets that are built on a 12,000-year history of farmer and breeder innovation. All of the diversity of crop varieties and breeds that we enjoy today come from this tradition of combining the art and science of public plant breeding with keen field-based observations and selections.

2012 marked the 150th anniversary of the laws that established the US Department of Agriculture and our land-grant university system. These laws intended to create a national infrastructure designed to expand US agriculture for the sake of prosperity and security, and develop advancements in agriculture accessible to all. At the heart of these efforts was a mission to support farmers who were actively building and improving our nation's germplasm through research, education, and innovation.

Two key objectives of instituting what we know now as the USDA and the land-grant system were identifying and distributing beneficial plant genetic resources, and conducting research in areas that were not profitable to burgeoning private ventures.

In recent years, public resources have shifted toward the area of genomic and molecular genetics. This shift poses a dangerous threat to this historic mandate and is contributing to the narrowing of our seed and breed diversity and the privatization of both genetics and breeding capacity.

The symptoms of this shift have been increasingly evident in the land-grant universities and farm fields of our nation for decades. Across the nation, once-strong public plant and animal breeding programs at our land grant universities have atrophied. Routinely, as conventional or classical breeders retire, their positions are not being refilled. New positions in the field are not being created. Graduate student interest in this field is declining because of fewer faculty resources and fewer research opportunities.

The erosion of public plant breeding capacity and public variety development is particularly critical for organic and sustainable farmers whose cropping and livestock systems depend heavily on adaptation of plants and animals to the unique soils, pest conditions and the changing climates of their areas. These farmers are also either prohibited from using genetically modified germplasm (in the case of organic farmers), or choose not to do so because of conflicts with their cropping systems (as is the case for many sustainable farmers).

But the need for reinvigoration of public plant and animal breeding goes far beyond organic and sustainable farmers. If we continue to allow the consolidation of our germplasm resources into an ever-narrowing pool, we eliminate our ability to adapt to changing global conditions, and jeopardize our food security.

Strengthening the diversity and adaptability of our seed germplasm is the best precaution against such food security vulnerabilities, especially in the face of the uncertainties associated with global climate change. Protecting existing agricultural genetic diversity and expanding available seed and breed diversity are essential to the future viability of family farms and our food supply.

Furthermore, classical breeding is a proven cost-effective complement to modern genomic techniques. Without classical breeding, we will continue to lose public seeds and breeds, a critical resource for American farmers, researchers, and for the stability of the global food supply.

The intent and spirit of the laws that created the US Department of Agriculture and our land grant university system have been lost. The need for public breeding programs to steward our diverse genetic diversity and deliver finished public cultivars is more important than ever.

To address this critical issue, RAFI organized the 2014 Summit on Seeds & Breeds for 21st Century Agriculture: Meeting the Challenges of Food Security, held March 5-7, 2014 in Washington, DC. The summit built upon work accomplished during two previous Seeds & Breeds summits, and information gathered from stakeholders and breeders around the country by RAFI and our partners.

The 2014 summit provided an opportunity for farmers, breeders, scientists and other leaders involved in public plant breeding and seed democracy to network, convene and engage in peer-to-peer learning. It also provided a critical opportunity to collectively explore and identify solutions to the challenges we face as we work to reverse the disappearance of our agricultural biodiversity.

Some of these challenges include:

• Disappearing agricultural biodiversity

• Lack of funding and support for classical/public breeding

• Increasing corporate control of seed industry

• Lack of public awareness on the issues, root causes, implications and potential solutions

• Disjointed community of plant breeders and farmers

The summit tasked attendees to collectively develop a set of recommendations to build a clear policy pathway through pre-conference paper development and workshop roundtable discussions. These recommendations include an assessment and revision of the national seeds and breeds policy blueprint with links to food security and climate change, including a national survey of public programs to determine the state of public breeding and cultivar development capacity.

The 2014 summit addressed the following issues:

- The need for longer, profitable and more diverse crop and livestock rotations that utilize and enhance locally adapted biodiversity of seeds and breeds, in order to strengthen resilience of U.S. and global food systems, to address the urgent needs for adaptation to climate change, and to better approach new regional market, agronomic and nutritional opportunities and challenges.

- Training and mentorship for the next generation of public plant and animal breeders to continue the highly successful and long history of public cultivar development, to better stabilize our land grant base of public cultivar developers, and to ensure these public seed lines will be utilized into the future.

- Strengthening our public germplasm collections that house a vast array of valuable genetic diversity including the current state of these collections, what is needed to ensure their long-term viability and how best to increase public access and utilization of these valuable public resources.

- Achieving more options for farmer seed choices by strengthening the long-term U.S. public commitment to public cultivar development. A common sentiment from a wide array of farmers and breeders, regardless of the productions systems they work in, is a need for greater options of where their seeds come from, greater access for sharing germplasm and research lines, and much more regionally appropriate choices.

- Establishing a dedicated funding and research capacity through the USDA and other public agricultural agencies. In periods of very tight budgets, public cultivar development through classical breeding methods are very cost-effective and much more economical than other lab-based approaches.

Organizational Background

Incorporated in 1990, RAFI traces its history back to the 1930's. RAFI works nationally and internationally, while rooted in North Carolina and the southeastern United States. Our work is guided by the belief that in order to ensure a safe, adequate supply of healthy food, we must protect family farms and encourage environmentally sound farming.

Our mission is to cultivate markets, policies and communities that sustain thriving, socially just and environmentally sustainable family farms. In advancing our mission, we work towards ensuring that the full diversity of seeds and breeds, the building blocks of agriculture, are reinvigorated and publicly protected. We do so by promoting policies that support public plant breeding, while also convening and organizing public plant breeders and farmers.

This area of work is one of our longest running and signature projects, dating back to the 1970's with the ground-breaking Frank Porter Graham Center Report on Seeds, a publication which helped trigger international debate, focus, and strategies that led to an international legally-binding treaty on biodiversity (the Convention on Biological Diversity). This publication also sparked greater awareness on the critical need to protect agricultural biodiversity and farmers' rights to seeds that are regionally adapted.

Today, our involvement in this area of work also includes the coordination of a national coalition of farmers, NGOs, and plant and animal breeders. The Coalition on Seeds and Breeds for 21st Century Agriculture advocates for a more focused deliberate and coordinated approach to the reinvigoration of public plant and animal breeding for public cultivar and breeds development.

The Seeds & Breeds for 21st Century Agriculture coalition exists to:

- reinvigorate our public plant and animal breeding capacity;
- ensure that regionally adapted public cultivars are readily available to provide greater farmer choice;
- prioritize support and train the next generation of public cultivar developers;
- protect, enhance and utilize our agricultural diversity to address the key challenges of 21st century agriculture.

Michael Sligh,
Rural Advancement Foundation International-USA (RAFI)

Executive Summary

Background

Agricultural biodiversity and site-specific plant and animal adaptation have sustained and nurtured communities around the world since the dawn of farming. The diversity of crop varieties and breeds that we enjoy today come from the combination of art and science of public plant breeding with keen field-based observations and selections. Never before have these cultural and biological resources been needed so much, nor have they ever been under such stress and threat.

As part of their long-term work to address seed and breed biodiversity and democracy, RAFI organized the Coalition for Seeds and Breeds for 21st Century Agriculture in 2003.

Since its inception, the coalition has worked to:

- Reinvigorate our public plant and animal breeding capacity,
- Ensure that regionally adapted public cultivars are readily available to provide greater choice to farmers,
- Prioritize support and training for the next generation of public cultivar developers, and
- Protect, enhance and utilize our agricultural diversity to address the key challenges of 21st century agriculture.

RAFI and the Coalition for Seeds and Breeds for 21st Century Agriculture organized the *2014 Summit on Seeds and Breeds for 21st Century Agriculture*. The summit builds upon work accomplished during two previous Seeds & Breeds summits and through information gathered from stakeholders and breeders around the country.

The summit was convened to address both the growing crisis in seed biodiversity and our global capacity to develop diverse seed and breed varieties. The purpose of the event, and key to this renaissance of resilience, was to address the need for more public cultivars and breeds that are regionally adapted, readily accessible to both breeders and farmers, and housed in the public domain.

Held in Washington, DC in March of 2014, the gathering brought together plant breeders, seed industry experts, farmers, activists, academics representing ten universities, twelve civil society organizations and four seed collections. This diverse group of experts came together to discuss the state of our global seed supply and develop recommendations for reinvigorating public breeding research and increasing seed availability in the country.

These proceedings provide a compilation of the summit's keynote papers, response papers, presentations and findings. It also provides a summary of the recommendations developed by participants during summit discussions, including short, medium and long-range recommendations and positive goals for reversing this crisis. Summit keynote papers were authored by well-known breeders and researchers in the field including:

- William Tracy, a sweet corn breeder with the University of Wisconsin;
- Major Goodman, a corn breeder and professor of crop science at North Carolina State University;
- Tommy Carter, a research geneticist and professor of crop science at North Carolina State University;
- David Ellis, the head of the Genebank Unit at the International Potato Center in Peru;
- Kathy Jo Wetter, Research Director of ETC Group's Action Group on Erosion, Technology & Concentration;
- Michael Mazourek, a vegetable breeder and professor of plant breeding and genetics at Cornell University; and
- Charles Brummer, Senior V.P. Director of Forage Improvement at the Samuel Roberts Noble Foundation.

Summit Findings

Based on keynote papers, response papers and discussion, summit participants identified the most critical challenges threatening the future of plant breeding.

Key summit findings can be summed up as seven major challenges:

1. Our current agricultural systems are increasingly vulnerable to weather and pest disruptions due to the decline of agro-biodiversity in our commercial seed choices. This vulnerability is especially important as we face shifting and unpredictable climatic conditions.

2. Public cultivars developed through classical breeding techniques are an extremely successful and powerful public asset and critical to addressing the increasing vulnerability of our agricultural systems. The lack of adequate funding and loss of institutional capacity have significantly reduced our ability for this critical public cultivar development.

3. Consolidation and concentration in the ownership of seeds have caused negative impacts on cultivar development, genetic diversity and farmer choice.

4. The adoption of utility patents has caused a decline of farmer and researcher access to and innovation in the development and adaptation of elite cultivars.

5. The number of public cultivar developers continues its decades-long decline, increasing the urgency for renewed institutional capacity to support the next generation of public plant breeders.

6. New and innovative partnerships and models for collaboration are critical to address more regionalized and participatory approaches to public cultivar development.

7. Public germplasm collections and the genetic resource conservation system lack adequate funding to steward our genetic heritage, and facilitate democratic access.

Summit Recommendations

1. Develop a comprehensive national plan to restore funding and institutional capacity for the development of public plant and animal varieties.

2. Encourage and reward agro-biodiversity on farms and in our commercial seed choices in order to increase resilience against shifting and unpredictable climatic conditions.

3. Address the negative impacts of consolidation and concentration in the ownership of seeds by empowering farmers to save and own seeds and encouraging more independent regional seed companies.

4. Increase farmer and researcher access to innovation in the development of elite cultivars, and confront the negative impacts of utility patents and restrictive licenses.

5. Increase the number of public cultivar developers in each of the seven US climatic regions with a focus on renewing institutional capacity to support future public plant breeders.

6. Create new, innovative partnerships and models to address regionalized and participatory approaches to public cultivar development.

7. Strengthen and democratize public germplasm collection systems and address germplasm access and sharing at an international level.

8. Commit adequate resources to determine critically missing data, budgets and baseline information to better articulate both the challenges and the solutions ahead.

9. Build greater public awareness of the importance of public cultivar development and of the positive solutions mapped out by this national summit. We can do this best by expanding our regional communities of seed advocates and identifying on-the-ground regional priorities and challenges to ensure that our solutions meet the needs of stakeholders in each region.

A Call to Action

This summit marks yet another call for greater action and is aimed at resetting our priorities with increased urgency and vigor. Public plant breeding is a critical tool to foster greater seed choices, longer cropping system rotations and much greater public utilization of our collective germplasm collections. These effects are crucial to increasing agricultural resilience to withstand and adapt to the coming challenges.

Unless action is taken quickly, we stand to lose both agricultural diversity of seeds and breeds and our capacity for public variety development. The future will be shaped by the magnitude of our response now. We must be clear and honest that we are not prepared. We are behind and must pick up the pace, especially as global conditions force us from more proactive to reactive responses.

CALL TO ACTION:

KEY FINDINGS & RECOMMENDATIONS

Call to Action: Key Summit Findings & Recommendations

"The future of the food supply demands diversity of genetics, diversity of cropping systems, and diversity of decision makers." Bill Tracy

Cultivar development in the public domain remains one of the most effective approaches to solving the seed challenges facing 21st century agriculture. The long and undeniable track record of significant increases in yields and effective responses to insect and disease resistance due to public cultivar development is clear. This is the proven and rational path forward that must be reinvigorated now to ensure meaningful options in the future.

However, the summit identified a series of obstacles and challenges to restoring public cultivar development, which demand immediate public attention and support. Restoring public cultivar development to its full capacity is imperative at this critical moment when these skills and the proven multiple benefits of public seed innovations are most urgently needed.

Key Findings:

A lack of adequate funding and loss of institutional capacity and support for public cultivar development.

Increased vulnerability of agricultural systems to weather and pest disruptions due to the decline of agro-biodiversity on farms and in our commercial seed choices in a time of shifting and unpredictable climatic conditions.

1. Negative impacts on cultivar development, genetic diversity and farmer choice due to consolidation and concentration in the ownership of seeds.

2. A decline of farmer and researcher access to and innovation in the development of elite cultivars due to adoption of utility patents.

3. The number of public cultivar developers continues its decade's long decline, increasing the urgency for renewed institutional capacity to support the next generation of public plant breeders.

4. New and innovative partnerships and models are critical to address more regionalized and participatory approaches to public cultivar development.

5. Public germplasm collections and the genetic resource conservation system lack adequate funding to achieve their critical mission of stewarding our genetic heritage, and facilitating democratic access.

For each of these major challenges, summit participants and the summit planning committee developed the following specific findings:

A lack of adequate funding and loss of institutional capacity and support for public cultivar development.

- Inadequate funding for competitive grants at USDA and other agencies targeted for public cultivar development, along with the concomitant loss of Land Grant University (LGU) capacity funding, has caused a significant decline in LGU ability to maintain meaningful support for public cultivar development. This will lead to the loss of future generations of public plant breeders due to the lack of well-funded and institutionalized career paths within the LGU system.

- We lack of a comprehensive federal plan for resolving this crisis. Such a plan would include: dedicated competitive grant pools of monies, reinvigorated LGU capacity and long term commitment to existing breeders, and clear support for the next generation of plant breeders. This must be coupled with the full array of scientists in related disciplines focused on public breeding challenges and needs.

Increased vulnerability of agricultural systems to weather or pest disruptions due to the decline of agro-biodiversity on farms and in our commercial seed choices at a time of shifting and unpredictable climatic conditions.

- Scientists present expressed great concern that all major crops currently planted are too genetically uniform and thus vulnerable to new diseases and pests. There is currently no monitoring or baseline data being collected and no federal plan for oversight to address this brewing crisis.

- The majority of cropland is managed with very short rotations of major crops such as corn and soy due to distorted federal policy incentives. This has led to geographically-focused intensive production areas, and the abandonment of the margins of these production regions by private-sector breeding programs. The major crops are now being bred to solve problems that develop in short rotations and intensive management, which only intensifies and perpetuates the problems. Examples include the evolution of pests and pathogens, to survive in these cropping systems, soil borne diseases, and saline or acidic soils.

- Our current agricultural system is based on cheap inputs derived from non-renewable resources that may not be relied upon long-term. Sustainable and resilient approaches are urgently needed, including more regionally-adapted cover crops, forage-based livestock systems and increased use of nitrogen-fixing cropping options.

- We are experiencing unprecedented weather changes with more erratic, extreme and unpredictable weather patterns. This will require more regionally adapted varieties of diverse species, soil building crops, and longer crop rotations with increased crop options to build greater food systems resilience.

- Heirloom and other locally adapted varieties require new improvements and re-adaptation to meet these changing conditions due to such rapid climatic changes.

Consolidation and concentration in the ownership of seeds has and continues to restrict cultivar development, erode genetic diversity and limit farmer choice.

- Many of these detrimental changes have been paralleled by concentration of seed ownership by three to five major companies. This has resulted in a decrease in private sector breeding for minor crops and the margins of primary production areas while increasing breeding effort on a few major crops and highly simplified cropping systems.

- This has now shifted far too much responsibility and decision-making for the future of our food security, crop diversity and cropping choices from the public to a handful of companies in the private sector. This is a recipe for food insecurity and an unprecedented narrowing of genetic diversity.

A decline of farmer and researcher access to elite cultivars and opportunity for elite cultivar development due to the adoption of utility patents.

- The growth of utility patents and restrictive licensing agreements by major seed companies and universities has greatly reduced the flow of scientific exchange and innovation and is a major contributor to the accelerated loss of farmers' rights to save seeds. Utility patents are often used in combination with PVP certificates, but PVP certificates alone with restrictive licensing agreements can also stop plant breeders and farmers from using seeds for replanting or breeding, halting innovation. Seed varieties developed with public resources must be held in the public domain, with no restrictions on research, use as parental breeding stock, or farm-saved seed.

- While patents and PVP are defended as being necessary for innovation, their current use poses a major violation of the intent of both the utility patent system and the plant variety protection act. In addition, farmers are increasingly seeking non-patented seeds because of the growing cost of such seeds, as well as need for new options to cope with rapidly growing weed and pest resistance problems.

- Marginalized farming communities remain underserved by current public and private plant breeding programs, and critically need access to more regionally adapted public varietals for their food security.

The number of public cultivar developers continues its decades long decline, increasing the urgency for renewed institutional capacity to support the next generation of public plant breeders.

- There is a continuing decline in the number of active public-sector cultivar development programs. Not only is this currently problematic, it also means that current experts are leaving without transferring their skills, expertise, and germplasm collections to a successor.

- Farmer check-off dollars support public sector cultivar development programs in a few crops. However, long-arc research aimed at addressing long-term systems challenges suffers even in well-funded major crops.

- Most crops do not have check-off funds, including forages, oats, clovers, barley, culturally significant crops, fruits and vegetables. Due to the lack of continuous improvements resulting in cultivar releases and long arc research the economic viability of all these crops is are all falling further behind those of the major commodities. This limits farmer options and cropping system diversity.

New and innovative partnerships and models are critical to address more regionalized and participatory approaches to public cultivar development.

- In order to respond to declining public funding for plant breeding and the changing needs of agriculture, new models for cooperation by farmers, LGU breeders, NGO's and progressive private-sector companies are urgently needed to respond to calls for more regionally adapted improved seed choices and to ensure greater farmer access to these seeds.

- Current initiatives demonstrate how such collaborations can accelerate cultivar development for specific regions, minor crops or marginalized production areas. There are currently too few examples and these are under-funded so alternative funding models should be explored.

Public germplasm collections and the genetic resource conservation system lack adequate funding to achieve their critical mission of stewarding our genetic heritage, and facilitating democratic germplasm access.

- Our regional, national, and international germplasm collections represent a vital common global resource, which is essential to addressing the major societal and environmental challenges of this century. However, these collections remain critically under-funded and understaffed.

- This is forcing triage decision-making regarding which collections will be kept up to date. The required and timely regeneration, characterization and evaluation of these enormously valuable collections are in real jeopardy and continue to fall behind precisely at the time they are most needed.

- New models for increasing public access, while accelerating revitalization and characterization of these collections are urgently needed.

- As one example, corn, which is the number one grain crop planted worldwide, now has fewer than five public breeders left in the US. This serves as a cautionary example of what happens when the public sector abandons its role in cultivar development. The combination of seed company consolidation, coupled with the use of utility patents and restrictive licensing agreements has resulted in fewer choices for farmers, particularly those outside of major corn-growing regions. This privatization of corn breeding has resulted in a narrow focus on a few production traits suited to corn grown in geographically-specific monoculture systems and a lack of focus on traits related to adaptation on the margins and traits that would be advantageous in more diverse rotations. Regions that 20 years ago were major corn production areas have been abandoned by the private sector and yield growth in those regions has stalled, decreasing the economic viability of farms and farming. This poses a great potential for corn genetic uniformity due to market demands and creates new food security vulnerabilities.

- Deferral of plant breeding to private rather than public programs represents a crucial loss of decision-making in the public interest.

Key Recommendations:

The seven challenges identified in the findings serve as the frame for the recommended solutions listed below.

1. Develop a comprehensive national plan to restore funding and institutional capacity.

2. Encourage and reward agro-biodiversity on farms and in our commercial seed choices in order to increase resilience against shifting and unpredictable climatic conditions.

3. Empower farmers to save and own seeds, encourage the development of more independent regional seed companies, and address the negative impacts of consolidation and concentration in the ownership of seeds.

4. Increase farmer and researcher access to innovation in the development of elite cultivars, and confront the negative impacts of utility patents and restrictive licenses.

5. Increase the number of public cultivar developers in each of the seven US climatic regions with focus on renewed institutional capacity to support next generation of public plant breeders.

6. Create new, innovative partnerships and models to address regionalized and participatory approaches to public cultivar development.

7. Strengthen and democratize public germplasm collection systems and address germplasm access and sharing at an international level. In addition, effective action on these critical issues is limited by both critical information available about the current state of seed and breed diversity, existing public capacity and funding programs. *We therefore add recommendation the next recommendation:*

8. Commit adequate resources to determine critically missing data, budgets and baseline information to better articulate both the challenges and the solutions ahead. Further action will also depend on increased awareness of these issues by LGU leadership, policy makers and the general public. *We therefore also add the following recommendation:*

9. Build greater public awareness of the importance of public cultivar development and of the positive solutions mapped out by this national summit. We can do this best by deepening and broadening our regional communities and identifying the on-the-ground regional priorities and challenges to ensure that our solutions meet the needs of stakeholders in each region.

Recommended Action Steps

The following recommended steps for action are broken down into short (S), medium (M) and long (L) range time frames ordered by sequential need and aimed at building enduring and meaningful solutions to the challenges and findings identified above.

Seizing the momentum and recognizing the urgency of this crisis is critical and will determine the range of options and responses available to us as a society. Our food security depends on actions taken now.

1. **Develop a comprehensive national plan to restore funding and institutional capacity.**

- (S) Organize a series of regional Seed Summits to set regional seed priorities and to broaden and deepen our sets of allies. This should build toward a new national policy agenda.

- (M) Develop comprehensive budget needed to fully fund the reinvigoration of public plant breeding systems; including increased access to and maintenance of germplasm collections.

- (M) Develop a national policy agenda aimed at annual appropriations and the 2017 Farm Bill, to address the need for long term, comprehensive funding. This should include commitments to rebuild regional LGU capacity, fund "whole plant" public plant breeding teams, and support mentoring of the next generation of such plant breeders. This plan should also address continuous improvements of current elite cultivars, and the long arc of plant breeding through long-term, stable and adequate funding for classical plant breeding that results in finished public cultivars.

- (M) Diversify federal competitive grant opportunities that can designate public plant breeding as a specific funding area. NIH, CDC, EPA, DOD opportunities should be explored, as well as greater focus and cooperation at USDA.

- (M) Diversify funding streams available to public plant breeders by ensuring that royalties come back to breeding programs, identifying philanthropic pools of money, and investigating other models such as consumer and crop-specific check-off funding.

- (M) Work with the philanthropy community to tie together the multiple issues where plant breeding is able to contribute to solutions, and explain the need for ongoing long-term funding for plant breeding programs. Complex issues are an easier sell for philanthropic pools of money than for competitive grants.

- (L) Establish adequate funding and institutional capacity and infrastructural support; including diversifying public cultivar development funding streams.

2. Encourage and reward agro-biodiversity on farms and in our commercial seed choices in order to increase resilience against shifting and unpredictable climatic conditions.

- (M/L) Develop and fund climate vulnerability study broken down by the seven US climatic regions and the role of public cultivars in addressing these challenges.

- (L) Address the vulnerability of our agricultural systems by encouraging and rewarding agro-biodiversity on farms and in our commercial seed choices, in order to increase resilience against shifting and unpredictable climatic conditions.

3. Empower farmers to save and own seeds, encourage the development of more independent regional seed companies, and address the negative impacts of consolidation and concentration in the ownership of seeds.

- (S) Conduct a seed industry market share study to examine effects of consolidation on innovation and competition in the marketplace. Market share data should be made public.

- (M/L) Encourage the development of more independent regional seed companies, reinvigorate state crop improvement associations, and address the negative impacts of consolidation and concentration in the ownership of seeds.

- (M) Antitrust laws must be enforced in the seed industry. Follow-up on and request outcomes and analysis of the stalled DOJ/USDA workshops on concentration.

4. Increase farmer and researcher access to innovation in the development of elite cultivars, and confront the negative impacts of utility patents and restrictive licenses.

- Create greater access and information sharing regarding National Advisory Boards by crop to prioritize and coordinate breeding efforts and to document baselines levels of genetic uniformity by crop.

- (S) Host a national symposium focused on public cultivar development and intellectual property rights to create action plans regarding the impacts of utility patents and other restrictive licensing agreements on the public seed sector. Advocate for appropriate cultivar development and royalty models, as they may be different by crop, program, and region.

- (M) Conduct a thorough analysis of the effects of Bayh-Dole on public agricultural research (especially public plant breeding) to inform what changes might be made in the law that would enhance benefit sharing.

- (M) Educate universities on best practices and approaches to ensure shared value and future innovation and to ensure royalties go to breeding programs to continue the development and release of public cultivars.

- (M) Address challenges plant breeders face with technology transfer offices by documenting evidence of the problem and providing good working examples to ensure products remain accessible to the public and serve the public good.

- (M) Document abuses of PVP and how this contributes to lack of access and innovation. Use this to initiate policy reforms to stops such abuses. Establish national policy that cultivars released and developed with public resources remain in the public domain and comply with the PVPA.

- (M) Create a breeder friendly system to access information about existing patents that may impact their work, including patents that are ending, making germplasm available. Create a system for reporting on and collecting examples of patents that are clearly an abuse of patent law (not novel, naturally occurring).

- (S) Evaluate current seed licensing agreements (contracts), develop model language to ensure that the agreements have sunset clauses and do not prohibit research; including cultivar development, and seed saving.

- (L) Confront concentration of seed ownership and restrictive intellectual property practices through modification of utility patents to include plant breeders' and farmers' rights, and modification of licensing agreements (contract law) to allow research and germplasm exchange.

- (S) Establish dialogue with the USPTO to understand the expertise of those reviewing utility patent applications on living organisms, including seed; and advocate for the creation of an expert panel of plant breeders to serve as a resource for examiners.

5. **Increase the number of public cultivar developers in each of the seven US climatic regions with focus on renewed institutional capacity to support next generation of public plant breeders.**

- Target goal of 70 new public plant breeders by 2020 with an annual budget of $40 million dollars.

- (S) Develop best practices for universities to support active cultivar development programs and find ways to mitigate the "publish or perish" syndrome. This could include counting cultivar releases as publications in tenure and promotion, returning to 12-month appointments instead of the current trend of 9-month appointments and increasing infrastructural support for field breeding programs.

- (S) Develop policy recommendations for what public plant breeders can do to ensure that their cultivars remain in the public domain. Provide contract model language for ensuring that royalties from cultivar sales are fairly redistributed back to breeding programs.

- (M) Develop policy recommendations on the proper roles and relationships between public cultivar development and genomic research, to ensure that public investment is driven by the needs for greater cost-effectiveness and sustainability and that these investments are actually increasing public cultivars.

- (L) Train the next generation of plant breeders to ensure continuity in breeding programs and to keep a critical mass of public plant breeders to address problems related to the "long arc of research. Address major risks to existing public cultivar development programs related to plant breeders retiring without a replacement.

- Create new innovative partnerships and models to address regionalized and participatory approaches to public cultivar development.

- (S) Document and develop effective models for partnerships between public breeding programs, regional seed companies, non-profit associations and Crop Improvement Associations.

- (L) Partnerships should hold down costs, accelerate commercialization and distribution of cultivars developed by public breeders, and return a royalty on seed sales to support public breeding. Ensure there are enough regional models for distributing public cultivars.

6. Create new, innovative partnerships and models to address regionalized and participatory approaches to public cultivar development.

- (S) Document, evaluate and promote existing effective models for participatory plant breeding programs that include farmers. Ensure that both models and policy reforms include farmer incentives for participation.

- (S) Reinvigorate models such as those established by agricultural Extension to support breeders in better understanding regional context and priorities. Better coordinate and encourage multi-state variety trial networks.

- (M) Create regional pilot practice standards for increasing on-farm agro-biodiversity through breeding, screening and seed saving activities within NCRS system with the goal of creating nationally recognized standards.

- (M) Encourage the commercialization of farmer-bred cultivars and partnerships between farmer-breeders and small seed companies.

- (M) Develop alternative legal models for community and farmer ownership of germplasm.

- (M) Create decentralized plant breeding models through systems for public plant breeders to mentor farmers in participatory plant breeding.

7. Strengthen and democratize public germplasm collection systems and address germplasm access and sharing at an international level.

- (M) Develop a comprehensive action plan to revitalize and obtain stable and sufficient support for U.S. germplasm collections; ensuring the protection, maintenance and timely regeneration of these valuable collections This should include characterization for public plant breeding objectives and increased accessibility.

- (M) Develop and pilot a model program for regionally-based farmer/breeder germplasm collection regeneration, evaluation and screening systems; including policy, funding, training and incentives to participate with the goal of including a new program in the next Farm Bill.

- (M/L) Develop regional priorities for "long arc research" and create interdisciplinary team approaches for accessing traits that are needed and may be in recalcitrant germplasm collections. Complex problems often require genes not in the current pipeline and a team approach is needed to find and incorporate them.

- (L) Address international germplasm access with the goal of facilitating bilateral exchange of materials. Develop policy and administrative strategies to increase the timely flow of germplasm to and from US collections to accelerate public breeder and farmer access.

8. Commit adequate resources to determine critically missing data, budgets and baseline information to better articulate both the challenges and the solutions ahead.

- (S) Develop and establish methodology and baseline data on genetic uniformity of crops planted in the US, with corn, wheat and barley as examples.

- (S) Using the agricultural census information, develop baseline data and assessment of current US commercial crop rotation patterns by region.

- (S) Develop metrics and (M) on-going tracking systems to measure progress, multiple benefits and quality in public breeding programs by tracking inputs of funds and other resources vs. output of public cultivars at LGUs, ARS and NGO's. This should also include tracking regional priorities to identify breeding gaps, and career trajectories of plant breeding graduates.

- (S) Follow-up the pilot survey of LGU's regarding number of public cultivar developers, number of public releases and active breeding programs by commodity and region. This survey should include questions about current budgets for research activities and cultivar development activities, and budgets needed to maintain an active cultivar development program.

9. Build greater public awareness of the importance of public cultivar development and of the positive solutions mapped out by this national summit. We can do this best by deepening and broadening our regional communities and identifying the on-the-ground regional priorities and challenges to ensure that our solutions meet the needs of stakeholders in each region.

- Develop a national campaign to educate the public, universities, government administrators, and policy makers on the values and benefits of public plant breeding and cultivar development through the development of definitions, rationales, and clear talking points. This campaign must challenge the assumption that private industry is filling the need for plant breeding and that there is no need for robust public capacity. This campaign must simplify our messages and create linkages between responses to climate change, the dangers of genetic uniformity, role of public investments, the demands for better nutrition and local foods, and the need for regionally adapted seeds.

- Strengthen and expand Seeds & Breeds coalition partnerships to provide a high visibility forum for public plant breeding issues.

- Develop an outreach strategy for plant breeders and farmers, especially those with mature and well-respected programs and farms to become spokespersons and mentors for other plant breeders and to the broader set of allies to advocate for public plant breeding. Public plant breeders and farmers need to be seen as the leaders calling for change.

Summit Agenda

Wednesday, March 5th *(Day One)*

3:00 - 3:30 pm	Welcome, Summit Goals and Ground Rules **Michael Sligh – Just Foods Director, Rural Advancement Foundation International-USA (RAFI)*
3:30 - 5:15 pm	Participant Introductions and Meeting Expectations
5:30 - 6:00 pm	**Opening Keynote:** "Food Security and the Role of Public Cultivar Development." **William F. Tracy – Friday Chair of Vegetable Research, Dept. of Agronomy, University of Wisconsin-Madison* . We read every day about the growing challenges concerning our global food security. What roles have and should public cultivars and breeds play and what are some of the best examples and needs from around the world?
6:00 - 6:15 pm	Participant Question and Answer

Thursday, March 6th *(Day Two)*

8:00 - 8:30 am	**Welcome Address** - **Michael Sligh – Just Foods Director, Rural Advancement Foundation International-USA (RAFI)*
8:30 - 8:50 am	**Keynote 1:** "The State of Public Cultivar Development." **Tommy Carter – Research Geneticist & Professor of Crop Science, North Carolina State University, USDA/ARS*. Are we losing public breeders who can develop appropriate finished public cultivars and breeds? And, if so, why is this a concern and how best should it be remedied?
8:50 - 9:00 am	Participant Question and Answer

9:00 - 9:30 am	**Panel 1: Comments and Responses** **Margaret E. Smith** – Professor, College of Agriculture & Life Science's Dept. of Plant Breeding & Genetics, Cornell University [NY] **Charlie Brown** – President, Brownseed Genetics [WI] **Steve Diercks** – Owner, Coloma Farms Inc. [WI]
9:30 - 10:00 am	Participant Group Discussion
10:30 - 10:50 am	**Keynote 2:** "What would 21st Century breeding programs look like if they were geared toward more sustainable agricultural objectives and goals?" **Kathleen Merrigan – Former Deputy Secretary, USDA*; *(Oral Presentation/No Paper)* Our cropping systems are too uniform with too short rotations and lack the resilience and local adaptation to respond to climate change or the calls for a more local and healthy food supply. What policies are needed to address this?
10:50 - 11:00 am	Participant Question and Answer
11:00 - 11:30 am	**Panel 2: Comments and Responses** **Adrienne Shelton** – Graduate Student, Agronomy Dept., University of Wisconsin-Madison [WI] **Margaret Mellon** – Science Policy Consultant; Former Senior Scientist with Union of Concerned Scientists [Washington, DC]
11:30 - 12:00 pm	Participant Group Discussion
12:00 - 12:50 pm	**Luncheon Keynote:** "Taking the Long View – Changes over time and what is a Future Course?"

	Major Goodman – William Neal Reynolds Distinguished, University Professor of Crop Science, North Carolina State University [NC]
12:50 - 1:00 pm	Participant Question and Answer
1:00 - 1:30 pm	**Congressional Perspective, Hill Challenges and Opportunities:** **The Honorable Jon Tester** – U.S. Senator, Montana [D-MT] **Brad Gentile** – Legislative Director, Office of The Honorable Chris Gibson, U.S. Representative for New York's 19th congressional district [R-NY19]
1:30 - 2:00 pm	**Farmer and Public Interest Perspectives:** **Ferd Hoefner** – Policy Director, National Sustainable Agriculture Coalition [DC] **Steve Etka** – Legislative Director, National Organic Coalition (NOC) DC] **Jan Ahlen** – Government Relations Rep., National Farmers Union [DC] **Ben Burkett** – President, National Family Farm Coalition [MS]
2:00 - 3:00 pm	Participant Group Discussion
3:30 - 3:50 pm	**Keynote 3:** "What is the state of our germplasm collections and how best can we utilize and democratize these collections?" **David Ellis – Head of Genrbank Unit, International Potato Center (CIP) - [Peru]*. We know that collectively our public germplasm collections house a vast array of very valuable traits much needed for addressing our changing agricultural systems. What is the state of these collections, what is needed to strengthen

them, and what are some of the best examples of public utilization and access.

3:50 - 4:00 pm	Participant Question and Answer
4:00 - 4:30 pm	**Panel 3: Comments and Responses** **Jane Dever** – Associate Professor, Cotton Breeder & Geneticist, Texas A&M AgriLife Research [TX] **Theresa Podoll** – FBC Management Team, NPSAS Farm Breeding Club [ND] **Joy Hought** – Director of Education & Outreach, Native Seeds/SEARCH [AZ]
4:30 - 5:30 pm	Participant Group Discussion for Keynote # 3 and Panel 3 plus remaining questions from the day's sessions.

Friday, March 7th *(Day Three)*

8:00 - 8:20 am	**Keynote 4:** "What are the key challenges in ownership of seeds and how best to resolve?" **Kathy Jo Wetter – Research Director; Action Group on Erosion, Technology & Concentration (ETC Group)* [NC]. Presenting keynote paper co-authored with Pat Mooney, Executive Director, ETC Group. In this session we will explore the impact of intellectual property rights and growing number of restrictive license-agreements on innovation and farmer/breeder access to improved cultivars and identify policy and practice strategies moving forward.
8:20 - 8:30 am	Participant Question and Answer
8:30 - 9:00 am	**Panel 4: Comments and Responses** **Jack Kloppenburg** – Professor, Dept. of Community and Environmental Sociology, University of Wisconsin-Madison [WI] **Kristina Hubbard** – Director of Advocacy &

Communications, Organic Seed Alliance [MT]

9:00 - 10:00 am Participant Group Discussion

10:30 - 10:50 am **Keynote 5:** "What kind of partnerships/ models are working and how best do we accelerate their adoption?" **Michael Mazourek – Assistant Professor, Dept. of Plant Breeding & Genetics, Cornell University - [NY] *(Oral Presentation/No Paper)*. How could we redesign breeding programs to connect with farmers (participatory programs), consumers, seed industries, etc.? How can we accomplish cooperative problem solving? Can private seed companies and/or public Land Grant Universities (LGUs) meet our current and future needs? If not, do we need new models?

10:50 - 11:00 am Participant Question and Answer

11:00 - 11:30 am **Panel 5: Comments and Responses**
Walter Goldstein – Executive Director, Mandaamin Institute, Inc. - [WI]
Jim Myers – Professor, Vegetable Breeding and Genetics, Dept. of Horticulture, Oregon State University - [OR]
Jared Zystro – California Research and Education Specialist, Organic Seed Alliance - [OR]

11:30 - 12:00 pm Participant Group Discussion

12:00 - 12:50 pm **Luncheon Keynote:** "Public Cultivar Development's Role in Responding to Climate Change" *E. Charles Brummer – Senior Vice President Director, Forage Improvement Division, The Samuel Roberts Noble Foundation*

12:50 - 1:00 pm Participant Question and Answer

1:00 - 1:30 pm	**Panel Discussion: What Have We Heard?** The Blueprint Moving Forward: What Have We Heard, What is Missing, and Where Do We Go From Here? In this session we will explore what we have heard about the kinds of research, cooperation, education and policy support needed to respond to challenges of food security. **Julie Dawson** – Assistant Professor, Dept. of Horticulture, University of WI-Madison [WI] **Juli Obudzinski** – Senior Policy Analyst, National Sustainable Agriculture Coalition, **Ron Rosmann** – Rosmann Family Farms[IA]
1:30 - 2:00 pm	Participant Group Discussion
2:00 - 3:00 pm	**Participant Group Discussion of Next Steps:** What is Missing and Where Do We Go From Here? Facilitated by *Michael Sligh – Just Foods Director, Rural Advancement Foundation International-USA (RAFI)*
3:00 - 4:00 pm	Concluding remarks
4:00 pm	Adjourn

Keynote Biographies

CHARLES BRUMMER is the Director of the Forage Improvement Division at the Samuel Roberts Noble Foundation and conducts research on alfalfa and tall fescue breeding and genetics. He received his B.S. degree from Pennsylvania State University and his M.S. and Ph.D. degrees from the University of Georgia. Previously, he was on the faculty at both Iowa State University and the University of Georgia as the forage and bioenergy crop breeder. His program focuses on practical cultivar development, germplasm evaluation and incorporation, breeding methodology improvement, and application of genetic markers into forage breeding. Brummer currently serves as the Editor-in-Chief of the Crop Science Society of America and is an associate editor of Bioenergy Research. He is currently President of the North American Alfalfa Improvement Conference and past-president of the Grass Breeders Conference.

TOMMY CARTER grew up in rural north Georgia, the son of a county extension agent. His love of plants and agriculture led him to study plant breeding at the University of Georgia and at North Carolina State University, and then pursue a career in soybean breeding with USDA as part of the ARS Soybean Unit located at NCSU. His thirty-two-year career has focused on increasing the impact of the world's genetic resources on agriculture and society. His journal paper describing the narrow genetic base of soybean is the 10th most highly cited article to be published in the journal Crop Science, since its inception in 1960 (Crop Sci. 34:1143, 1994). Carter has developed 9 soybean cultivars, and 15 germplasm releases. Carter has also led a national program of 7 scientists for 10 years to develop drought-tolerant soybean cultivars using germplasm from Asia as parental stock. The original and subsequent drought-tolerant germplasm discoveries by Carter and project members have been the basis for most drought-tolerance advances in U.S. soybean. He identified the first drought-tolerant soybean types and reported the first QTLs for aluminum, salt, and drought tolerance in soybean. He transferred more than 200 breeding lines to industry via MTAs.

DAVID ELLIS is committed to the preservation of plant genetic resources with decades of experience in academia, private industry and the public sector. He leads the genebank at the International Potato Center (CIP) in Lima, Peru, maintaining the global in-trust collections of potato, sweet potato and Andean root and tuber crop. CIP is among 15 centers of the Consultative Group on International Agricultural Research (CGIAR), dedicated to reducing rural poverty, increasing food security, improving human health and nutrition, and ensuring sustainable management of natural resources. His research interests span plant development, medicinal compounds in plants (taxol), plant molecular biology, plant and insect ecology, cryobiology and conservation of plant genetic resources and diversity. Ellis has collected Mexican teosinte (the immediate ancestor to maize), worked with native American tribes to preserve plant genetic resources and is currently working with indigenous communities in the Andes. He previously served on the advisory board for the Desert Legume Program, as past associate editor of In Vitro Cellular & Developmental Biology–Plant, board member for the Society for In Vitro Biology and as a fellow for the Society for In Vitro Biology.

MAJOR GOODMAN directs the Department of Crop Science at North Carolina State University. The program focuses on the improvement of maize through the application of quantitative genetics theory and the incorporation of exotic germplasm in traditional maize breeding. Goodman received a B.S. in Mathematics from Iowa State University, with a minor in Chemistry, and an M.S. and a Ph.D. in Genetics with a minor in Statistics at NCSU. Among his many accolades, he served as a member of the Rockefeller Maize Germplasm Committee in 1972-75, he served as three-fourths chair of the USDA Maize Crop Advisory Committee in 1981-86 and three-fourths chair on the advisory panel for Maize Genetics Stock Center in 1985-86.

MICHAEL MAZOUREK is the Calvin Noyes Keeney Professor of Plant Breeding in the Department of Plant Breeding and Genetics at Cornell University. His work focuses on the improvement of peppers, peas and cucurbits (squash, melon, pumpkin, watermelon and cucumber) for growers by increasing yield and production traits, consumers through enhancing flavor and convenience characteristicsand the environment through pest and disease resistance that allow reduced pesticide usage. In addition to developing new cultivars with these traits, he trains students in plant genetics and plant breeding and shares these techniques with farmers interested in on-farm participatory breeding. These new seeds are created through traditional cross-pollination techniques and aided by new approaches in genomics that allow insight into the underlying science while still being compatible with certified organic seed. Mazourek received his Ph.D. from Cornell University in 2008.

KATHLEEN MERRIGAN served as the U.S. Deputy Secretary of Agriculture from April 2009 to March 2013. Merrigan helped develop USDA's organic labeling rules while head of the Agricultural Marketing Service from 1999-2001. She has also worked at Tufts University as Director of the Agriculture, Food and Environment Program. In 2010, Merrigan was featured as one of TIME Magazine's "100 Most Influential People of the Year." She holds a Ph.D. in environmental planning from the Massachusetts Institute of Technology. breeding and shares these techniques with farmers interested in on-farm participatory breeding. These new seeds are created through traditional cross-pollination techniques and aided by new approaches in genomics that allow insight into the underlying science while still being compatible with certified organic seed.

WILLIAM F. TRACY is professor and chairman of the Department of Agronomy, University of Wisconsin-Madison. He served as interim dean of the College of Agricultural and Life Sciences in 2012 and 2013. Tracy received his B.S. and M.S. in Plant Science from the University of Massachusetts Amherst and a Ph.D. in Plant Breeding from Cornell University in 1982. Following graduation he worked as a corn breeder for the International Plant Research Institute and Cargill, Inc. In 1984, Tracy joined the department of agronomy as an assistant professor and sweet corn breeder. Tracy leads one of the few remaining public sector sweet corn breeding programs in the U.S. Varieties developed by his program are grown around the world, for both conventional and organic cropping systems. Tracy is current chair of the Maize Crop Germplasm Committee, and president of the board of directors of the International Sweet Corn Development Association.

KATHY JO WETTER is the Research Director at ETC Group, an international research and advocacy organization. ETC Group monitors corporate concentration in the ever-expanding sector once known as "life sciences" and tracks emerging technologies and their impacts, or potential impacts, on marginalized communities. For more than 13 years, Wetter has contributed to ETC Group's research and analysis on the ownership, control, social and environmental impacts of technologies, including nanotechnology, agricultural biotechnologies (e.g., seed sterilization and so-called climate ready crops), synthetic biology and geoengineering. She holds a Ph.D. from the University of North Carolina at Chapel Hill.

SUMMIT PAPERS

Opening Keynote: "Food Security and the Role of Public Cultivar Development"

Author: William F. Tracy

We read every day about the growing challenges concerning our global food security. In this opening keynote paper, Tracy addresses the following question: What roles have and should public cultivars and breeds play and what are some of the best examples and needs from around the world?

WILLIAM F. TRACY is professor and chairman of the Department of Agronomy, University of Wisconsin-Madison. He served as interim dean of the College of Agricultural and Life Sciences in 2012 and 2013. Tracy received his B.S. and M.S. in Plant Science from the University of Massachusetts Amherst and a Ph.D. in Plant Breeding from Cornell University in 1982. Following graduation he worked as a corn breeder for the International Plant Research Institute and Cargill, Inc. In 1984, Tracy joined the department of agronomy as an assistant professor and sweet corn breeder. Tracy leads one of the few remaining public sector sweet corn breeding programs in the U.S. Varieties developed by his program are grown around the world, for both conventional and organic cropping systems. Tracy is current chair of the Maize Crop Germplasm Committee, and president of the board of directors of the International Sweet Corn Development Association.

FOOD SECURITY AND THE ROLE OF PUBLIC CULTIVAR DEVELOPMENT

William F. Tracy[1]

"To see things in the seed, that is genius." Lao Tzu

Our food system is in deep trouble. While we focus on the remarkable yield increases in a few crops and regions, we ignore problems that threaten our long term food security.

Our great food producing areas are treated as extractive economies with all the problems associated with coal country.

- Environmental degradation
- Soil erosion far beyond replacement rates
- Surface and ground water pollution
- Dead zones
- Depleted aquifers
- Salinization
- Desertification
- Air pollution and greenhouses gases
- Poverty and declining incomes
- Depopulation

Wendell Berry said *"We need to quit thinking of rural America as a colony. Too much of the economic history of our land has been that of the export of food, fuel, and raw materials, that have been destructively and too cheaply produced."* (Berry, 2005; 26)

We also see other symptoms of a food system on the brink.

- Hunger
- Diet related diseases
- Food deserts
- Abandonment of the margins
- Entire crops at risk such as citrus, dessert bananas, coconut
- Loss of biodiversity
- Concentration of decision makers
- Concentration of ownership of elite genetic material

[1] University of Wisconsin-Madison

What are we to do? Clearly the current systems are failing us and future generations. What does plant breeding have to do with this? A great deal! Plant breeding impacts each of the problems I have outlined, for good or bad. Access to adapted, high performing cultivars is required for the success of cropping systems. In turn, without varieties adapted to local environments and cropping systems, the best-designed cropping system will fail.

But why are we so concerned abut public cultivator development? Don't the big plant breeding life sciences companies have this covered? Aren't they spending billions of dollars on improving crops?

The short answer is that the private sector is very good at some things, fair at others, and totally ignores still more.

My many good friends and former students are doing an incredible job increasing corn and soybean yields in the Corn Belt and making these crops more efficient and easier to grow.

Others are doing the same for cotton and canola and a few other crops in their respective regions. But, we must remember that the sole purpose of for-profit corporations is to generate income for their stockholders. This is as it should be and the successful companies are very good at it. It is not their job to reduce soil erosion, water pollution, the loss of biodiversity or the abandonment of the margins. And it is certainly not their job to democratize access to elite plant germplasm.

But then who is responsible for attacking these serious issues? Clearly the public sector, writ large. We are here because we know that public cultivar development is a key component in addressing these problems. It falls to public plant breeders to develop cultivars that help address these crucial issues.

My friends in the major corporations are incredibly effective at developing high yielding, profitable row crops. But to reduce environmental degradation we must have more perennials on the landscape. This is not in the interest of people making most of their income on row crop agriculture. For more perennials on the landscape, we need adapted, high yielding, nutritious forages that will increase the profitability of grass based systems making them a viable economic alternative to row crop monoculture. This is but one example.

To reverse population decline and poverty in rural America and abandonment of the margins, we need regionally adapted cultivars that will create value-added, wealth-attracting economies rather than wealth-exporting economies. The revolution we are seeing in local foods and beverages demands locally adapted cultivars.

To increase biodiversity, and create economically viable rural economies all across our country we need a diversity of public sector breeders working on diverse crops, in diverse locations. And we need a diversity of approaches ranging from phenotypic mass selection to genomic selection. But the people doing this work *must develop* commercially competitive cultivars, and not just publish papers.

The *only* solution to the vexing problem of concentration of elite germplasm in the hands of a very few, and the allied problems of people in the global south being distrustful of sharing crop germplasm with others, is for public sector plant breeders to actually develop elite competitive cultivars that they then insure remain in the public sector.

Let me reiterate here, *public plant breeders must breed competitive cultivars!* Development of breeding technologies and gene mapping don't count! Germplasm enhancement or pre-breeding don't cut it! Cultivars! Cultivars! Cultivars that real farmers and ranchers and gardeners actually grow. Without this, changes in IP laws will not solve the problem of concentration of elite germplasm in private hands. Only public plant breeders creating elite commercially competitive cultivars will solve this problem.

But, myriad are those who say that this cannot be done by public breeders. Regrettably among that host, are the majority of public plant breeders themselves.

We know that public plant breeders can breed commercially successful varieties and that this can be done even in the most intensively bred crops. Many of the breeders in this room have developed commercially competitive cultivars. So as not to risk overlooking anyone by attempting to create an inclusive list, I will only mention one individual. Professor Major Goodman of North Carolina State has developed numerous inbreds that make hybrids that are competitive with those from the big hybrid corn companies.

Unfortunately, as I understand it, Major has found it easier to breed elite corn germplasm than to get NCSU's tech transfer group to understand the role of public plant breeding. This is the second challenge of creating and maintaining elite public germplasm pools: getting tech transfer agencies and university administrators to recognize the crucial and fundamental role of public cultivar development in democratizing the seed system. While I say that public plant breeders must breed new cultivars, that is not to say that the public breeders should duplicate the efforts of the private sector. Indeed the most remarkable thing about Major's success is that many of his competitive inbreds are 100% tropical germplasm (Uhr and Goodman. 1995; Tarter et al., 2003). This is something that many in the private second did not believe possible.

There is a long list of major innovations that have come from the public sector: semi-dwarf small grains, all the important endosperm mutants of sweet corn, Canola, hybrids, double haploids, the famous corn inbred B73 (which still underpins the hybrid corn industry 40 years after its release), drought tolerant soybeans, high anthocyanin tomatoes and nematode resistant cotton. The list goes on and on.

In many, perhaps most, of these cases, industry knew of these developments and their potential, yet actively resisted change. I know the sweet corn story (Tracy, 1997) best, but I don't think it is rare.

In 1953, Professor John Laughnan, a geneticist at the University of Illinois, was doing research on the genetic linkage of the genes a1 and sh2, and apparently he decided to pop a kernel in his mouth. Later he published his research in the journal Genetics (Laughnan, 1953). In this article he included a sentence that is pretty unusual for that journal. He wrote that the kernels of sh2 “are unusually sweet and have a pleasant malty flavor.”

Knowing that most sweet corn breeders didn’t read Genetics, Laughnan then published a brief report in the trade magazine The Canner (Laughnan, 1954). In this article he discussed the benefits for farmers and consumers; longer shelf life and harvest window and very favorable taste test results. We now know that Laughnan was correct on these predictions. However, in The Canner article, he was mistaken on one important point. He stated “Soon private companies will be actively engaged in introducing the new shrunken factor into preferred sweet lines.” That did not happen.

Laughnan, as a faculty member at the University of Illinois, would have been expected to discontinue this work at that point. He had done the underlying science, alerted the industry and other researchers to the exciting possibilities, and made his seed stocks freely available. No funding for this research was available, and he had major teaching and research responsibilities. But, like many pioneers, he saw opportunities where others did not and probably ignored obstacles that others saw as insurmountable.

Laughnan began a breeding program of his own. He backcrossed the sh2 allele into a number of established inbreds. Then, he had to create enough hybrid seed for evaluation. Since no financial support was available, he planted hybrid seed production blocks on rented land and he and his sons maintained these plots, which included the laborious work of detasseling the seed parent.

In the January 1961 issue of Seed World, Laughnan announced that his new hybrid would be available for the 1961 planting season from Illinois Foundation Seeds Co (IFS) (Laughnan, 1961). ‘Illini Xtra Sweet' was enjoyed by many, but it did not displace the traditional hybrids and few commercial breeders paid much attention to sh2. But this hybrid created the Japanese sweet corn industry and is still grown today. Laughnan never received a penny for his novel variety.

Meanwhile in Belle Glade, Florida, the heart of Everglades sweet corn production, Professor Emil Wolf realized sh2 might be the solution to the problems of Florida sweet corn producers. Thirteen years later Wolf released Florida Staysweet (Wolf, 1978). Eventually a descendant of Staysweet became an important hybrid in Florida, displacing hybrids from the commercial sweet corn companies. It also created the Taiwanese sweet corn industry. Laughnan's and Wolf's inbreds were the public germplasm that served as the genetic basis for all supersweet hybrids grown today.

Today supersweet is the dominant type of sweet corn, but the industry actively resisted working with the gene for nearly 30 years. I know commercial breeders who were told by their bosses not to work on sh2. It was only through the efforts of Laughnan and Wolf, two public employees, that supersweets became a crop and created industries around the world benefiting US seed producers.

Some large corporations are inherently conservative and lack nimbleness. Once they chart a course turning back can be difficult. For example, given the investment in genomic selection technology, it is hard to conceive of an event that would allow the major companies to abandon this approach, even if it was found to be no more efficient than phenotypic selection. Indeed it would hard for anyone within the company to admit that they had found the new technique wanting. As Upton Sinclair said '*It is difficult to get a man to understand something when his salary depends upon his not understanding it.*' (Sinclair, 1935).

Over the next day and a half, we will discuss the current status of public plant variety development; Tommy Carter and Major Goodman will give you information on the history and current state of public variety development programs, David Ellis and Kathy Jo Wetter will talk about the state of our germplasm collections and the impact of IP on germplasm and cultivar development and Kathleen Merrigan, Michael Mazourek, and Charlie Brummer will give us their thoughts on what the public cultivar system should look like moving forward.

What is the state of U.S. public plant breeding today?

In a word, variable – depending upon the crop, the institution, and the individual breeder.

A few programs are quite healthy, such as many of the western small grains programs. These programs are usually funded by check-offs, royalties or both. The principle risk to these programs is how they respond to intellectual property issues surrounding transgenics (GMO) and other technologies, and direct buyouts by corporations.

Other breeding programs are vibrant because of the drive of an individual breeder. However, these are transitory even ephemeral, dependent on that breeder and when the breeder moves on the program will likely be dropped or simply forgotten.

Many of the remaining programs are zombies, the walking dead, mere shells of their former selves – breeding programs in name only. Their only products are papers. When a breeding program stops producing improved germplasm it loses any links it once had to the real world.

And of course many programs are indeed dead (Guner and Wehner, 2003: Traxler et al., 2005). No breeder, no students, no germplasm, nothing. Once a program ends it is quite difficult to restart. Restarting a breeding program with the objective of creating new cultivars is much more difficult than restarting a research program, creating new knowledge. Once the pipeline is empty it takes many ears to fill.

I will say that the current outlook for public cultivar development is slightly more positive than it was 10 years ago. This is in no small measure due to the Seeds and Breeds coalition and our allies. We have more public cultivar developers from more states represented in the room today than we had ten years ago. We have far more graduate students active in applied public cultivar development programs. Organic Agriculture Research and Extension Initiative (OREI) has had a major role in this and we look forward to continued positive impacts from the renewal of that program and the specialty crops research initiative

(SCRI). The efforts of the major companies in funding graduate fellowships in plant breeding must be recognized as well as the incredible Seed Matters program of the Clif Bar Family Foundation funding 10 or so students. These are positive and exciting developments but we are still losing public cultivar development programs. We still have a long way to go.

Where must we go?

Predicting the future is seldom looked upon as scientific. Instead it is the purview of fortunetellers, cable channel psychics, and meteorologists.

As I explain in my 2003 Seeds and Breeds paper, "*What is Plant Breeding?*" (Tracy, 2004), plant breeders ***are*** expected to predict the future. Since new breeding projects started today will not reach the market for at least five years we must predict the future.

- What will American agriculture look like 10 to 20 years from now?
- More petroleum based inputs or fewer?
- Greater diversity of crops and cropping systems or fewer?
- More perennials on the landscape or more row crops?
- More concern about environmental degradation or less concern?
- More interest in local foods produced in a sustainable way or less?

I can guess what answers most of you would like to see for these questions. But I regret to say that I asked these same questions at the 2005 seeds and breeds, and with the exception of local foods, the rest have gone in what most of us would consider the negative direction.

Unlike many who deny or dither about the future, to be successful a plant breeder must firmly come down with a prediction. ***But by predicting the future, plant breeders determine the future.*** If a breeder predicts that high levels of aldicarb will be available to kill nematodes, then will she develop pest resistant cotton cultivars? If a breeder predicts that rotational grazing is a passing fad, how many grazing tolerant cultivars will she develop?

What can public plant breeders offer?

Food Security: To quote Cary Fowler (2004) *"Plant breeding programs are a form of social insurance. In times of crisis, when new diseases appear or old ones evolve and explode with virulent outbreaks, plant breeders are called upon to rescue crops, industries and people."*

Plant breeding decisions determine the future of the world's food supply. Placing the responsibility for the world's crop germplasm and plant improvement in the hands of a few companies is bad public policy. The primary goal of private corporations is to make profit, and even in the case of the most civic-minded corporations, this profit motive will be at odds with certain public needs. Even if we assume that a crop was the purview of only one or two well-intentioned public sector breeders it is extremely dangerous to have so few people making decisions that will determine the future of a crop. Even well intentioned people make mistakes. The future of our food supply requires genetic diversity but also demands a diversity of decision-makers (plant breeders).

Sustainability: Diversity at multiple levels leads to a more sustainable agriculture. Genetic diversity, crop diversity, cropping system diversity, farming system diversity, community diversity, and intellectual diversity are needed. The merger-acquisition model of late 20th century continues today. Justification for such activity includes efficiency of scale, which by definition works against diversity. As acquisitions occur in the seed industry, large geographical areas are abandoned (abandonment of the margins).

Farmers in these regions are left to use old non-competitive cultivars or ones that were developed elsewhere and just happened to fit their needs. This results in those farms producing less desirable products and reduced income potential and threatens the future of those farms. Loss of these farms decreases diversity at the community level. Numerous public breeders working in diverse ecosystems with diverse crops are needed to increase diversity at all levels.

Independence: Ideally, public plant breeders have minimal direct market constraints on their breeding program. Therefore decisions may be made in the public interest. Public breeders should be able to focus on solutions that do not necessarily result in high seed sales volume, such as long-lived perennials. Public breeders can focus on pest resistance without worrying about loss of pesticide sales. Public breeders can pursue risky ideas and use exotic difficult-to-incorporate germplasm without worrying about quarterly reports.

Economic competiveness of alternative cropping systems: Food production is an economic endeavor. Farmers and producers will choose cropping systems that will sustain them and their families. The commercial seed sector is very good at developing highly efficient corn and soybean cultivars that increase the ease of production and maximize the farmer's profitability. If we wish to have more diverse cropping systems we need other cropping systems that return similar profits to the farmer. Perennials must play a key role, as must cropping systems based on complex rotations. But for these systems to work, the crops in these rotations must have value.

Elite public germplasm pools; new businesses and seed systems: Regardless of changes in intellectual property laws, the only way to ensure that elite germplasm remains in the public domain is to have vigorous and healthy public sector cultivar development programs. We also need public sector tech transfer programs that understand the purpose of land grant cultivar development programs, and in turn have as their mission democratizing the seed sector rather than balkanizing it.

Having elite germplasm available to be used freely by anyone in the world will begin to rebuild trust between the people of the germplasm rich global south and those of the germplasm poor, technology rich north.

Elite publicly available germplasm will also allow more entrepreneurs to enter the seed sector, creating new models and new markets. Many of these new companies will appear in the abandoned margins, enhancing the economies of some of these marginalized areas. We are already seeing this.

Community service: Plant breeders actually developing cultivars adapted to the local environment must be familiar with the needs and challenges of local farmers and consumers. Presumably this means talking to them and walking their fields.

What do we have to do to create the kind of agriculture we need to sustain and nurture humanity and the other species with which we share the planet?

We need to develop systems that support and empower those who do cultivar development in the public sector. We need to increase the number of public plant breeding programs and make public plant breeding an attractive career option to future public cultivar developers. We need to make sure that elite germplasm developed by public cultivar developers is available to others for crop improvement. We need to do these things not just in the U.S., but globally.

In closing I quote from Wendell Berry's (Berry, 2005; 102) Kleper lecture that he gave at the Crop Science meeting in Seattle, 10 years ago.

"*Our recent focus upon productivity, genetic and technological uniformity, and global trade-all supported by supposedly limitless supplies of fuel, water and soil-has obscured the necessity for local adaptation. But our circumstances are changing now, and this requirement will be forced upon us again by…depleted soils, aquifers, and streams and the spread of exotic weeds, pests, and diseases… And we are going to have to resume breeding of plants and animals to fit the region and farm.*"

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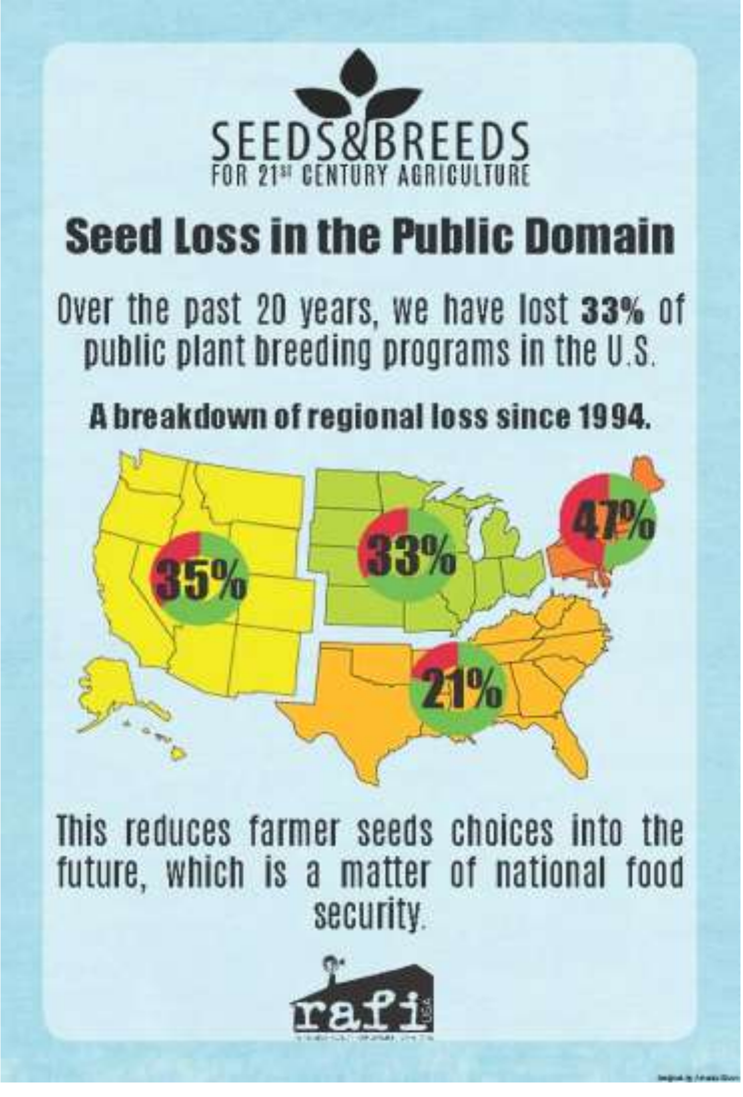
Keynote Paper # 1: "What is the State of Public Cultivar Development?"

Authors: Thomas E. Carter, Jr., William F. Tracy, Thomas R. Sinclair
Thomas G. Isleib, Richard Joos

TOMMY CARTER grew up in rural north Georgia, the son of a county extension agent. His love of plants and agriculture led him to study plant breeding at the University of Georgia and at North Carolina State
University, and then pursue a career in soybean breeding with USDA as part of the ARS Soybean Unit located at NCSU. His thirty-two-year career has focused on increasing the impact of the world's genetic resources on agriculture and society. His journal paper describing the narrow genetic base of soybean is the 10th most highly cited article to be published in the journal Crop Science, since its inception in 1960 (Crop Sci. 34:1143, 1994).

WILLIAM F. TRACY is professor and chairman of the Department of Agronomy, University of Wisconsin-Madison. He served as interim dean of the College of Agricultural and Life Sciences in 2012 and 2013. Tracy received his B.S. and M.S. in Plant Science from the University of Massachusetts Amherst and a Ph.D. in Plant Breeding from Cornell University in 1982. Following graduation he worked as a corn breeder for the International Plant Research Institute and Cargill, Inc. In 1984, Tracy joined the department of agronomy as an assistant professor and sweet corn breeder. Tracy leads one of the few remaining public sector sweet corn breeding programs in the U.S. Varieties developed by his program are grown around the world, for both conventional and organic cropping systems. Tracy is current chair of the Maize Crop Germplasm Committee, and president of the board of directors of the International Sweet Corn Development Association.


SEEDS&BREEDS
FOR 21ST CENTURY AGRICULTURE
Seed Loss in the Public Domain
Over the past 20 years, we have lost 33% of public plant breeding programs in the U.S.
A breakdown of regional loss since 1994.
35%
33%
47%
21%
This reduces farmer seeds choices into the future, which is a matter of national food security.
rafi USA

WHAT IS THE STATE OF PUBLIC CULTIVAR DEVELOPMENT?

Thomas E. Carter, Jr.[2], William F. Tracy[3], Thomas R. Sinclair[4], Thomas G. Isleib[5], Richard Joost[6]

Overview

Numerous papers have reported what is common knowledge among public and private breeders- the number of public plant breeders has decreased markedly over the past several decades. In this presentation, we report the results of a recent survey of public breeding programs, present case studies for public breeding in three crops, and describe factors which may affect the sustainability of current public breeding programs. Lastly, trends in "whole plant" or crop physiology are compared to public breeding for "lessons learned" that may aid in the sustainability of public plant breeding.

What is plant breeding, really?

Pipeline breeding

New varieties are continually developed and released as part of the overall breeding pipeline for plant improvement. Some estimates indicate that plant breeding improves yield of seed crops by about 1% per year, as a result of pipeline breeding, especially in row crops (Fehr, 1984). The breeding pipeline concept is vital to plant breeding, and deserves some explanation. This often used, but seldom defined, phrase turns out to be integral to understanding the current state of public breeding

[2] USDA-ARS Soybean and Nitrogen Fixation Unit, 3127 Ligon St., Raleigh, NC 27607
[3] Department of Agronomy, College of Agricultural and Life Sciences, University of Wisconsin- Madison, 1575 Linden Dr. Madison, WI 53706 (wftracy@wisc.edu)
[4] Department of Crop Science, North Carolina State University, Box 7629, Raleigh, NC 27695
[5] Department of Crop Science, North Carolina State University, Box 7629, Raleigh, NC 27695
[6] Director of Supply Programs, United Soybean Board Smith Bucklin,16305 Swingley Ridge Road, Suite 120, Chesterfield MO 63017

in many crops. For large acreage crops, the breeding pipeline typically refers to incremental, cyclical, streamlined breeding within an established gene pool. This cyclic breeding, in effect, pyramids favorable 'small effect' genes into new cultivars, which are then released in series, each slightly better than the last. Because pipeline breeding moves new agricultural breeding products to market quickly, commercial investment in plant breeding usually targets pipeline breeding.

Problem solving via the long *"Arc of Research"* – A vital role for public breeding

Although very important to breeding impact and success, pipeline breeding cannot be considered the sole approach to plant improvement. Important problems that do not fit the pipeline breeding model continually arise in agriculture. By their nature and definition, these problems are new, not resolved, or not well understood. Thus, they are not even part of established pipeline breeding programs. The primary reason that many problems require a specialized research approach is that genes controlling the traits of interest often do not exist in the applied/elite breeding gene pool. In those instances, breeding success, i.e. moving solutions into pipeline breeding, is often achieved only after a very long "*arc of research*", where the path from the first discovery of appropriate parental stocks to final deployment of high yielding varieties carrying these traits can take decades.

Examples of traits that do not fit the normal pipeline breeding concept, but nicely match the long arc of research model are nematode resistance, development of "heart smart" oils for the consumer, and incorporation of stress-tolerance to mitigate climate change. Advances in all of these areas have required their own unique problem-solving approach, related to the genetics and phenotype of the trait. In soybean, the soybean cyst nematode and the first genetic source of resistance to it were discovered in the 1950's (Carter et al., 2004). A genetic resource resistant to virtually all races in the field was not discovered until the 1980's, and release of high yielding cultivars with near immunity did not occur until after 2000, and then only for specific regions. A program to improve soybean oil composition was launched in the 1970's and genetic discoveries have been ongoing since then. Specialty varieties with improved oil composition have been grown on only limited acreage to date, although adapted varieties with improved oil are under development (Wilson, 2004). The first drought tolerant soybean type was identified in the 1980s, and the first drought tolerant cultivar will likely be released in 2014 (Purcell and Specht 2004). Problems that fit a long arc of research are usually resolved through a long-term, sustained public-sector effort, rather than through the private sector. The reasons are 1) financial return on investment, although substantial, can be slow in developing (and, thus, not suited to short-term commercial business plans), 2) the research path to success is usually high risk and often subject to setbacks, and 3) solutions almost always need multidisciplinary (and multi-institutional) team efforts common to the public sector. In the context of meeting future needs (the focus of this conference), it is important to mention that in crops where acreage is dominated by private pipeline breeding, it is these complex agricultural problems where the long arc of public research is essential. This is an important "reason to be" for public breeders. Even in crops with little or no private pipeline breeding, solving complex problems *via* the long arc of public breeding research remains critically important.

- **Long term trends for the numbers of public plant breeders**

Although the public plant breeding community by its nature is ideally suited to tackle long term complicated problems, it is an understood, but seldom stated, assumption that public breeding programs will actually be present in the future to solve the agricultural problems that we know today and those that will surely come. However, it is rather clear from the past three decades that one cannot assume that public programs will always be around to solve the next crisis. Frey (1996) identified 217 breeders who released cultivars in 1994, and Traxler et al. (2005), [which included Frey as an author], reported 144 plant breeders involved in cultivar development in 2001. These data indicate an approximate 34% decline in number of breeders in the approximate 6 year period from 1994-2001. The decline described above and in many other papers appears to be correlated with 1) the expansion of private breeding, fostered by PVP laws and patenting, that protect owners and promote investment, and 2) decreased public grant support for field-oriented research, in favor of rapidly advancing areas such as plant transformation and molecular biology (Frey, 1996).

- **Increase in private breeding**

The move toward privatization of corn breeding began in the 1960's, before most other crops, because of the yield advantages of superior hybrids and "built in" ownership protection in that the harvested crop cannot be saved economically as planting seed, because of inbreeding depression. With the advent of patented GMO herbicide tolerance technology and patented commercial varieties in the 1990's, the private sector greatly expanded its crops list for commercial breeding to include self-fertilizing species that are marketed primarily as true-breeding or mostly true breeding varieties, such as cotton and soybean. Patent protection of private varieties essentially eliminated planting of "bin run" seed by farmers and stopped the unlicensed use of these new varieties as a pollen source for future breeding by other companies. In soybean, the first GMO herbicide tolerant varieties were marketed in 1995, and quickly expanded from small acreage to occupy approximately 95% of the current annual 70 million-acre crop. Private breeding efforts now essentially dwarf most public soybean programs, with an individual commercial breeder evaluating as many as 100,000 yield plots per year in his/her program. An average public soybean breeding program would likely be less than one third the size of a private program. This expansion has caused some decline in public soybean breeding, simply because of the perception that the commercial pipeline is sufficiently large and robust to solve all problems.

In cotton, the private sector has long been a part of cotton breeding. Private cotton breeding accelerated in the 1990s and was further advanced through GMO insect and herbicide tolerance technology, so that today almost 98% of the cotton acreage is planted in private varieties (Smith et al., 1999; Bowman, 1999; Bowman et al., 2006). Only a very few public cotton breeders are now developing varieties which are competitive with private products.

- **Decrease in federal and**
  10. state grant opportunities

The trend for an overall reduction in public funding for field-oriented plant breeding coincides with two major incidents in the 1980's. In 1982, the Winrock Report (Rockefeller Foundation, 1982) indicated essentially that more federal funding and university positions were needed for molecular genetics. In 1984, Horsch et al. of the Monsanto Company reported the regeneration of plants from transformed *Nicotiana plumbaginifolia* cells, ushering in a new era in plant molecular genetics. Federal and state funding for research has risen only modestly since the 1980s, but the shift in research priorities has been dramatic. Support for public breeding and crop physiology was nearly eliminated, causing field research to decline.

- **Current estimates of public plant breeders releasing cultivars**

In December of 2013, a survey was developed and emailed to the heads of all crop science, agronomy, plant science, and/or horticulture departments at the 1862 Land Grant Universities. The survey concentrated on the number of current public cultivar development programs and whether the number had changed, compared to 20 years ago. The department heads were asked for the number of public cultivar development programs and not plant breeders in non-cultivar development roles. This tactic was taken because many administrators responding to surveys on plant breeding inevitably equate cultivar developers with individuals doing any kind of genetic research on economic plants. The entire survey questionnaire is found below (Appendix A.). To increase response and transparency, the survey was kept quite short and the responders were told that the data would only be released in aggregate. Seventy-five requests were sent out and 39 individuals responded.

Because not all universities responded to the survey, our current summary of public cultivar development programs is incomplete. For example, we know that the number of university wheat and soybean breeders releasing cultivars is underestimated in the survey. However, important trends can be noted. The 39 responding department heads reported a total of 141 cultivar development programs, and they also reported that their institutions collectively had a total of 210 programs twenty years ago, a 31% decrease over the two decades. This new estimate of 210 is quite close to Frey's previous estimate of 214 cultivar development programs in 1994 (Frey, 1996). However, our estimate does appear to converge well with that made by Traxler et al. (2006). Although all three surveys report only breeders who are, or were, actively developing cultivars, it is possible that the working definition of cultivar development program may have varied among the responders as well as the organizers of the surveys. For example, if a plant breeder is devoting only 10% or as much as 90% of a program to cultivar development, there could be ambiguity in counting "active breeders." It should be noted that the 210 programs from 20 years ago, identified by department heads, are not synonymous with the number of breeders developing cultivars, because in many cases, especially for vegetables and forages, individual breeders are working on multiple crops. The breakdown by regions for respondents shows roughly similar downward trends across the country (Table 1). Only one university noted an increase, though slight, in the number of breeders over the past 20 years.

The crop with the most reported public cultivar development programs is wheat with fifteen followed by soybean with eight. Significantly, with the exception of turf, all crops with five or more cultivar development programs are either highly self-pollinated or clonally reproduced. Many, but not all, turf species are selfers or apomicts. The number of programs in Table 1 (134) is less than the reported 141 because the number of crops given in response to Question 3 did not always match the single number given in response to Question 2.

Based on the survey responses, it is clear that for many crops the amount of effort devoted to public cultivar developments is minor (Table 2). For a few crops including field corn, soybeans, tomatoes and peppers substantial private sector efforts are underway, but rarely do these private sector efforts pursue the long arc of breeding research associated with problem solving. For the vast majority of crops, many of which are critical to our food supply, the private sector investment is not much greater than the public effort. Table beets, for example, have one public program and one private program. There are five public oat breeding programs and perhaps two in the private sector. In 1964, there were 17 public sector and at least 10 private sector programs breeding sweet corn inbreds and hybrids for the temperate zone. Today there is one public sector and six private programs. Among the vegetables only potatoes, tomatoes, and all types of cucurbits combined have more than two programs developing cultivars (each with five). Some universities have greatly curtailed investment in public breeding. At Clemson University for example, the number of plant breeders dropped to only two in 2012. This number increased to three in 2013.

- **Specific crop trends: three case studies**

Although the general trend for public plant breeding is down, crops vary drastically in the resiliency of public breeding. By relying on the expertise of the authors of this paper, we determined that: corn has 5 public plant breeders, down from a peak of 25 in 1960's, when there was one public breeder per corn-growing state on average (Goodman, 2014); soybean has 20 public university breeders, down from a peak of about 25 in 1985 (Table 3; Carter et al. 2004);

and the number of university peanut breeders has actually increased slightly from 7 to 8 during 1985 to the present (Table 4). As late as the mid-1970s, all land grant universities in the 12 states of the north central region had field corn cultivar development programs. Today, only two remain, one in North Dakota on the far margin of the Corn Belt and the other a silage breeding program in Wisconsin.

Examining the breeding history of corn, soybean, and peanut, we identified four factors that appear to promote sustainability of public breeding: 1) availability of financial support from farmer commodity groups, 2) ability of public programs to generate revenue through royalties, 3) limited competition from private breeding in a crop, and 4) a high degree of positive interaction between public and commercial breeders in crops where the commercial sector is active. In the case of peanut, limited private breeding, commodity support, and royalties have all combined to keep public peanut breeding at a steady level over decades. In soybean, strong commodity support from the United Soybean Board (USB), positive collaborations with a strong commercial breeding sector, and revenues from cultivar releases all appear to play roles in maintaining a critical mass (through a diminishing number) of public soybean breeding positions over time. In corn, most of the positive factors sustaining public breeding are absent and likely have contributed to the great loss of public corn programs.

- **Factors contributing to the sustainability of public plant breeding**

Farmer commodity support

An important factor affecting public breeding is farmer support. As an example, the USB and allied state soybean check-off research programs have strongly supported public soybean research for the past twenty years. Research activities supported by USB are broad and substantial, including basic research such as genomics, and gene discovery, and the sequencing of the soybean genome (Schmutz, et al., 2010). More recently USB has invested heavily in research to explore the molecular basis of gene expression. Several projects have used RNAseq next generation sequencing to determine gene expression in response to various conditions and stages of plant development. In addition, other studies are exploring how gene expression is regulated through transcription and epigenetic factors.

Importantly, however, the funding for basic research has been balanced by funding for more applied breeding and crop physiological studies for trait improvement. These more applied efforts include development of QTL markers for marker assisted selection, the development and testing of breeding methods, as well as a major expansion of the U.S. breeding pool through extensive germplasm development, using novel Asian breeding stock. Nearly 70% of USB's over $13.8 million investment in public research in fiscal year 2014 is invested in molecular genetics or plant breeding efforts for soybean. Of this, several million have gone directly to public soybean breeders and their collaborators (plant pathologists and plant physiologists).

Although commercial companies have extensive soybean breeding programs, they rely on basic exploratory breeding research by public programs to identify new sources of genetic diversity for agronomic traits of interest. This is a key factor in the USB commodity group's decision to fund public breeding research into trait identification and development of improved germplasm. Key efforts that benefit commercial variety development are the exploration of exotic germplasm for new sources of yield QTL and pest resistance genes. In addition, public researchers funded by the commodity checkoff have identified two major sources of drought tolerance in soybean, involving the "slow canopy wilting" and improved symbiotic nitrogen fixation activity during drought stress. All of these advances were accomplished in the public sector after private varieties began to dominate the market place.

The drought tolerance studies exemplify the major contributions that can come from funding cooperative public programs in breeding and physiology. One stream of study resulted from observation in the field of slow wilting by a few plant introductions from the USDA germplasm collection. These lines were found to be successful parents in producing drought-tolerant progeny. Physiological studies indicated that the slow wilting trait in PI 416937 was associated with limited transpiration under dry atmosphere conditions (Fletcher et al., 2007) and that this behavior was a result of a low leaf hydraulic conductance (Sinclair et al., 2008). Evaluation of progeny lines in the field showed, as anticipated, that slow wilting was associated with improved water use efficiency and soil water conservation (King et al., 2008; Ries et al., 2012).

Another stream of research funded by the USB check-off program was the sensitivity of nitrogen fixation to soil drying. A search of 3500 lines of soybean resulted in the identification of eight lines that express substantial tolerance to soil drying (Sinclair et al., 2000). More recently, the key advantage of the slow-wilting genotype PI 471938 was found to be its nitrogen fixation drought tolerance (Devi and Sinclair, 2013). Working with breeders, the lines identified in the physiology studies have now been used to generate germplasm (Chen et al., 2007; Devi et al., 2104). This advanced germplasm has contributed directly to commercial breeding programs for the development of drought tolerant soybean cultivars.

In 2007, the soybean check-off made a commitment to train the next generation of soybean scientists by initiating the USB Ph.D. Fellowship program administered by the American Society of Agronomy. Eleven Fellows have participated in the program since its inception with three having completed their degrees and entered the workforce. Many of these fellows are receiving education in the plant breeding arena. In addition to the Fellowship program, over 30% of the research funding by USB goes toward graduate or post-doctoral education. Many of these positions are breeding oriented. This is key evidence that training of the next generation of plant breeders is a critical side benefit of commodity funding.

Peanut has a national check-off program similar to that of soybean. Historically, a large share of peanut funding has been used for plant breeding. At the national level, the majority of current funding supports molecular research, including sequencing of the peanut genome, identification of DNA markers for use in MAS, and phenotyping associated with QTL identification. At the state level, perhaps 50 to 70% of peanut commodity funding is directed toward public cultivar development plus applied research aimed at problems that fit the "long arc" of research concept, such as disease resistance.

Royalty streams generated by public programs

With the imposition of royalties or research fees on publically developed cultivars, a new revenue stream was established to help support public breeding efforts. To remain consistent with public institutional policy on other types of "inventions," some part of the royalty payments is usually given to the "inventors," *i.e.*, the breeders and others who contributed to cultivar development. The remaining portion of the royalty is split among the university, college, and departmental administrations, and importantly, about 10-20% returns to originating breeding program. The rules for dispersing royalties vary with the institution, and are sometimes subject to agreements made between institutions and sponsors of breeding work.

Personal remuneration has caused some friction within and among universities, the USDA-ARS, private seed companies, and the seedsmen who handle new public releases and have to come up with the royalties. In general, however, seedsmen support royalty collection as long as most is returned to the breeding programs to generate more variety releases. Even so, financially strapped administrators often see the royalty revenue as an opportunity to replace shortfalls in appropriations and seek to use it for purposes other than for the breeding of the particular crop generating the revenue. Despite the potential problems with royalty collection and dispersion, royalties have helped keep public breeding programs viable at many universities. For example, annual peanut royalties often exceed $400,000 at North Carolina State University and $2,000,000, at the University of Georgia. Total annual revenue from plant breeding in all crops typically exceeds $2,000,000 and $4,500,000 at these respective institutions.

Interaction with commercial breeders

A good case study of positive interaction between public and commercial breeders is soybean. In this crop, the role of the public breeder has shifted drastically from 1995 to the present. In 1995, public breeders heavily pursued pipeline breeding aimed directly at farmers, but also devoted considerable attention to problem-solving "long arc" breeding research. Today, although many public programs continue to release non-GMO varieties, and some are releasing competitive GMO varieties, the breeding emphasis has shifted to specific problem solving strategies aimed at providing new breeding stock for commercial programs.

This transition has been fostered in part by United Soybean Board funding which focuses on a series of problem areas well suited for public sector breeding. This successful transition has also been promoted by good dialogue between public and private breeders. In 2008, 52 public and private breeders and geneticists met for two days in St. Louis and addressed the question, 'What Should Public Breeders Be Doing?' From this discussion, a "white paper" was developed with the title "A Strategic Plan for Public Soybean Breeding". In this meeting, the shift in roles for public breeders was acknowledged and priorities were identified for the future.

The education of the next generation of plant breeders was identified as a continuing important role. One priority topic perhaps less obvious to non-soybean breeders was that of supplying new germplasm to the private sector. Prior to patenting of plant material, germplasm exchange among public and private breeders was fairly routine, and fostered a great amount of genetic recombination in the applied breeding pool and many successful cultivar releases. An unanticipated consequence of patenting was that germplasm exchange among competing commercial breeding programs became far more limited. The net effect was that, genetic materials became more closely related within a company than between companies. To avert this impending bottleneck of diversity within companies, the white paper identified as a high priority the development of new and diverse genetic materials as breeding stock by the public sector. The public sector has responded with the help of USB and state commodity groups by developing new genetic recombinants in the applied pool, but also by breeding with exotic Asian land races. In this way, the public sector has added new genes (alleles) to applied breeding that lift yield ceiling, protect against biotic and abiotic pests, improve seed value and composition, and increase the overall genetic diversity available for crop breeding.

The overall interaction between public and private breeders has increased, with private breeders serving on graduate committees, and collaborating with public breeders on specific new research problems such as resistance to soybean rust, the soy aphid, and the kudzu bug. All parties are very mindful of intellectual property (IP) claims and the ownership rights of respective institutions in such endeavors. In most cases, scientists have created win-win situations that have made the collaborations successful. Industry has endowed chairs for soybean breeders, provided grant support, and collaborated on an 'in kind' basis to promote research. Commercial breeders also participate in USB supported grant workshops to plan research.

Prospects for interactions between public plant breeding and crop physiology

The demographic trends in crop physiology tend to mirror those in public breeding (Fig.1). Sinclair found that membership in the plant breeding and genetic resources (C1) division and plant physiology (C2) division of the Crop Science Society of America declined equally, with a decline of 56% among physiologists from 1990 to 2010. These results for plant breeders show a percentage decline that roughly agrees with that found in earlier surveys (Fey, 1996; Traxler et al., 2005). Although Division C1 membership involves both public and commercial breeders, it is commonly known that the number of private breeders is rising not falling in the USA, and, thus, changes in private breeding are not likely to explain any of the downward trend in membership (Traxler et al., 2005). Anecdotal corroborating evidence for the increase in private breeding is noted in that the great majority of graduating Ph.D. students in plant breeding are hired by the private sector.

The ushering in of the genomic era and subsequent decrease in public grant support is likely responsible for the marked decline in the number of whole plant" or crop physiologists in the public sector (Boote and Sinclair, 2006). This decrease in scientists who seek to identify and understand traits useful in breeding programs (e.g. abiotic stress tolerance) appears to have been even more crippling than in public plant breeding. Where crop ecology was a vibrant research topic 30 and 40 years ago, it has essentially disappeared from academic investigation. [Universities claim to offer "agroecology" curricula but these programs are almost always programs in sustainability rather than basic investigations on plant-environment interactions that impact crop yield.] The shift in public funding from whole-plant physiology to molecular genetics has essentially stymied the capacity to train a new generation of scientists to investigate and integrate the plant processes impacting crop performance. Very few universities have even one whole-plant physiologist who has the resources to interact with breeders in germplasm identification and enhancement. A crisis situation has developed, where we may no longer have a critical mass of public scientists to address problems that require a "long arc of research" for effective solutions.

Graduate training in whole plant physiology has fared so poorly, that few universities are currently producing students in this area. There is shortage of crop physiologists in the private sector as a result. In plant breeding, we have not dropped below the critical mass needed to train graduate students. For students interested in plant breeding, Guner and Wehner (2003) indicated that only eight universities graduated at least seven students per year in plant breeding from 1995 to 2000, showing that the number of universities with the critical mass to train students may be declining. Monsanto and other companies have provided graduate assistantships to "buoy up" or sustain academic programs in plant breeding. However, long term effects already observed in crop physiology suggest that further reductions in public plant breeding, if not checked, may lead a crippling effect on the ability of many universities to train Ph.D. students in plant breeding.

Conclusion

Our view is that the strongest argument for continuation of public breeding programs, regardless of the crop, is the long arc of research required for solving important agricultural problems. Without the long view inherent to public plant breeding, and the public plant breeding infrastructure to address novel emerging threats, the nation's and world's food supply is at risk. The public breeding track record in meeting food security challengers over the past several decades is extensive and continuing. Because the number of public plant breeders is on the decline, we recommend that public breeders critically examine the factors enhancing the sustainability of their profession and vigorously pursue crop-specific as well as national options to enhance plant breeding. In that regard, we suggest that farmer commodity support is especially critical to the future of public plant breeding. All of our findings suggest that increased financial and stakeholder support, in whatever form they may take, are essential to the future of plant breeding of major commodity crops.

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Table 1. Survey of Public Plant Breeders at State Agricultural Experimental Stations in 2013. The survey is based on responses of department heads at universities.

REGION	Plant breeders NOW	Plant breeders 20 YEARS AGO	Numbers of Programs now compared to 20 years ago	RESPONDANTS
	no.	no.	%	no.
North Eastern	24	41	59	9
North Central	41	61	67	10
Western	26	40	65	6
Southern	50	63	79	6
Total	141	205	69	31

Table 2. Number of public cultivar development programs reported by 39 department heads at Land Grant Universities in 2013.

Crop	Number of cultivar development programs
wheat	15
Soybean	8
woody ornamentals	7
Barley	6
Berries	6
tree fruits and nuts	6
dry bean	5
Oat	5
Potato	5
Tomato	5
Turf	5
Alfalfa	4
Sorghum	4
field corn	3
Cotton	3
Flowers	3
Forages	3
Ornamentals	3
Peanuts	3
Canola	2
Citrus	2
Lettuce	2
peppers	2
pumpkins	2
rice	2
squash	2
switch grass	2
carrot	1
celery	1
chickpea	1
cucumber	1
cucurbit (unspecified)	1
dry pea	1
flax	1
horseradish	1
meadow foam	1
lentil	1
onion	1
popcorn	1
rye	1
sweet corn	1
sweet potatoes	1
table beets	1
tobacco	1
triticale	1
vegetables (species unspecified)	1
watermelon	1
winter legumes	1
Total	136

Note: Independent estimates based on contact with experts in plant breeding indicate as many as 20 soybean, 8 peanut, 35 wheat, and 6 university corn breeders

Maybe actively developing cultivars.

Table 3. Soybean breeders involved in cultivar release in 1990 and 2014.

Estimates are derived from contacting experts in the field and are not part of a formal survey.

	1985			2014		
State	**Total**	**Federal**	**State**	**Total**	**Federal**	**State**
AL	1		1	0.5		0.5
AR	1		1	1		1
FL	1		1	0		
GA	1		1	1		1
IA	2		2	2		2
IL	2.5	0.5	2	2.5	0.5	2
IND	1	1		1		1
KS	1		1	1		1
KY	1		1	0		
LA	1.5		2	1		1
MD	1		1	0		
MICH	1		1	1		1
MN	1		1	1		1
MO	2		2	2		2
MS	1	1		2		2
NC	2	2	0	3	2	1
ND	0			1	1	
NE	1		1	1		1
OH	3	1	2	1		1
OK	1		1		0	
TN	1		1	1		1
VA	2		2	1		1
WI	0.5		0.5	0		
TOTAL	29.5	5.5	24.5	24	3.5	18.5

Table 4. Peanut breeders involved in cultivar release in 1985 and 2014.

Estimates are derived from contacting experts in the field and are not part of a formal survey

Region	1985		2014	
	Breeder	**Institution**	**Breeder**	**Institution**
Virginia-Carolina area				
Virginia	Coffelt, T.A.	USDA-ARS	--	
North Carolina	Wynne, J.C.	NCARS	Isleib, T.G.	NCARS
South Carolina	--		Tallury, S.P.	SCAES
Southeastern area				
Georgia	Branch, W.D. Hammons, R.O. Harvey, E. Moore, K.	GAES USDA-ARS Private Private	Branch, W.D. Holbrook, C.C.	GAES USDA-ARS
Florida	D.A. Knauft Gorbet, D.W.	FIFAS FIFAS	Tillman, B.L.	FIFAS
Alabama			Chen, C.	AAES
Southwestern area				
Texas	Smith, O.D. Wilson, J.	TAES Private	Burow, M.A. Baring, M.L. Wilson, J.	TAES TAES Private
Oklahoma	Kirby, J.	OAES	Chamberlin, K.D.	USDA-ARS
New Mexico	Hsi, D.	NMAES	Puppala, N.	NMAES

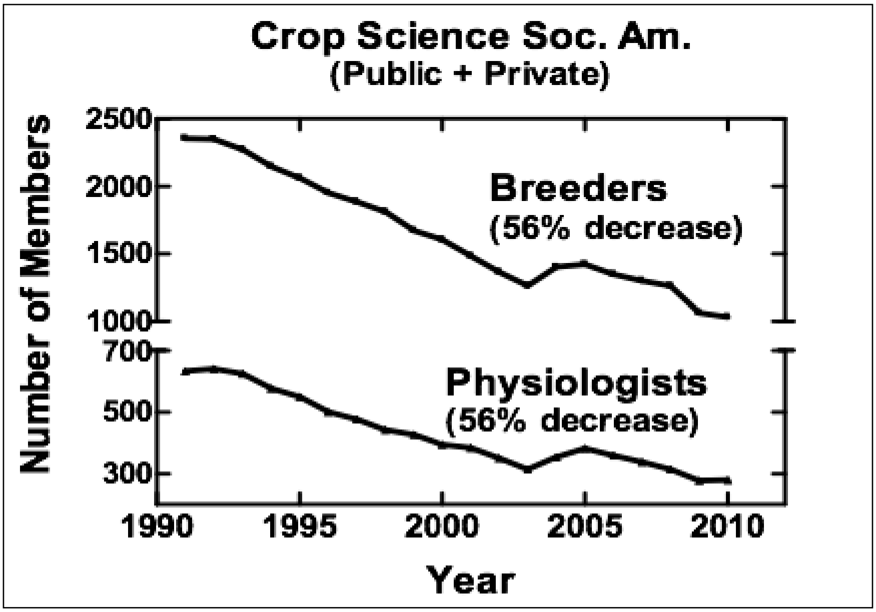

Table 1: Membership in the C1 and C2 Divisions of the Crop Science Society of American Over Decades

Response to ***"What is the State of Public Cultivar Development?"*** by Margaret E. Smith

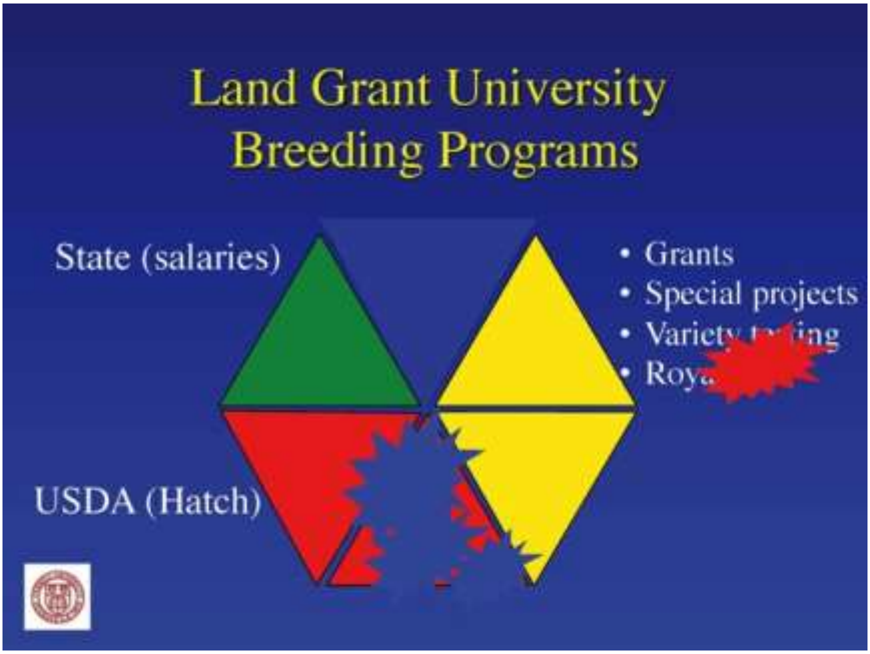

Figure 1: Land Grant University Breeding Program Decline

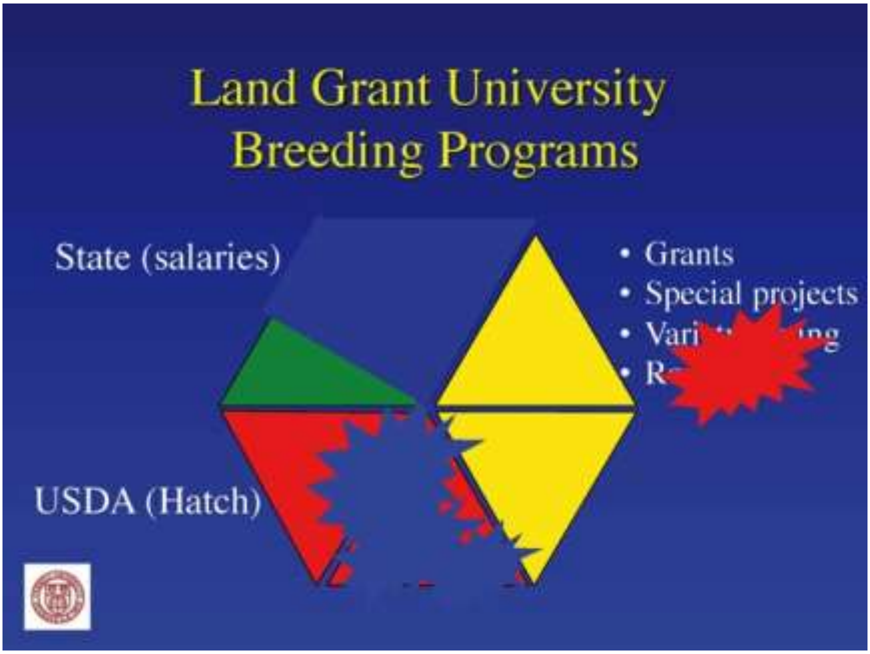

Figure 2: Land Grant University Breeding Program Decline

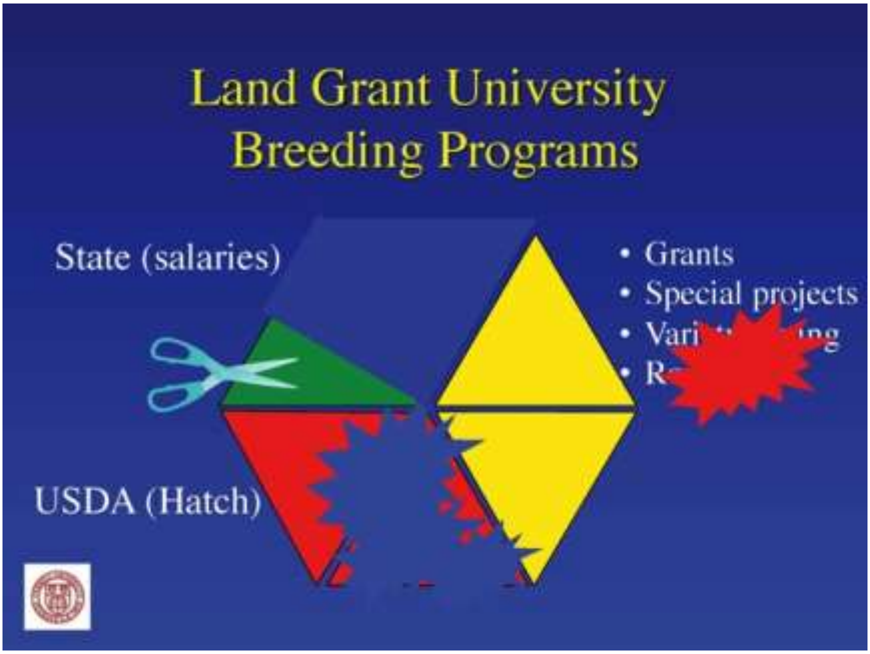

Figure 3: Land Grant University Breeding Program Decline

RESPONSE TO "WHAT IS THE STATE OF PUBLIC CULTIVAR DEVELOPMENT?"

T. CARTER, W. TRACY, T. SINCLAIR, T. ISLEIB, AND R. JOOST,

Margaret E. Smith[7]

In this excellent analysis, the authors have summarized well the trends that are apparent in public sector breeding positions and noted some of the factors that tend to support (or discourage) continued public sector plant breeding efforts. In my response, I would like to highlight how this has played out for field corn, arguably the predominant agricultural crop in the U.S., and particularly how it has played out in our New York state-based public sector breeding program. Clearly this is the case study that I am most familiar with, but I also aim to draw from it some lessons that I hope will be more generally applicable to sustaining public sector plant breeding programs.

In 2013, corn was grown on 93.9 million acres nationally and 1.2 million acres in N.Y. – the largest acreage row crop at both the state and the national levels. In some states, corn enjoys strong commodity group support, which is one of the factors that Carter et al. note as contributing to the sustainability of public sector programs. In N.Y. corn is grown both for silage to support the dairy industry (about half the state acreage) and for grain as feed and for commodity sales. Those farmers growing corn for silage generally perceive themselves first and foremost as dairymen, not corn growers, so most are not associated with the Corn Growers Association. This likely explains, in part, why the N.Y. Corn Growers Association has tried, but failed, to pass any kind of a check-off that might support research (including public sector plant breeding). Thus there is no commodity group support in N.Y. for the predominant agricultural commodity in the state.

Cornell University's public sector plant breeding programs were historically supported by a combination of funding streams. State funds supported the salaries of faculty running the breeding programs and, perhaps even more importantly, the salaries of long term field technicians and research farm support staff – the highly specialized and broadly talented people who are able to help keep crops, machinery, field plots, and breeding programs thriving, well organized, and effective. Federal formula funds (Hatch) provided a reliable annual allocation to support the core annual expenses of a breeding effort. Then

[7] Department of Plant Breeding and Genetics, Cornell University

each crop had supplemental funding from various sources (competitive grants, industry, commodity groups, special projects, etc.) to build on this essential framework.

The challenge that breeders have faced since that time has been the erosion or elimination of pieces of that essential framework upon which a breeding program can be built. Like most land grant universities, the state allocation to Cornell has declined over the last few decades. We now call ourselves a "state assisted College" rather than a "state supported College". The faculty salaries are still provided by state funds – no small contribution. Our department chose to take repeated state budget cuts over the last few decades in areas other than field technician support, because we recognize the critical importance of experienced, long-term employees to breeding programs. Despite that, the College has now withdrawn all state funds from supporting technician positions in individual research programs. Their support must all come from grant sources. We are fortunate that our Hatch funds continue to contribute, but since Hatch allocations at the federal level have remained constant, they have clearly declined in real dollar terms and requests for such support have increased across the College. So even that piece of "*core*" support has been steadily eroding.

As funds that supported the core of breeding programs gradually eroded, fees charged to private companies and/or growers became part of the funding mix that sustained breeding programs. For example, breeders began charging seed companies for part of the cost of extension variety testing, as a means to help support the infrastructure and personnel needed to test both commercial varieties as well as the products of their own breeding efforts. With the intellectual property provisions of Bayh-Dole legislation, universities began to view plant breeding programs as potential revenue generators through licensing and royalties that could be charged on their varieties. The hope for major revenues was bolstered by examples such as the University of California – Davis strawberry breeding program, which has reportedly grossed $4.7 million in royalty payments. However, the structure of the strawberry industry and associated breeding efforts is entirely different from that for most agronomic crops and many horticultural crops. In any case, breeding programs came to rely more heavily on these revenue-based sources of funds as other sources declined.

At Cornell University, the next blow to funding came in the form of changes in policy that affected both variety testing fees and royalty income. University policy with respect to extension variety testing shifted much closer to policy governing industry-sponsored research, reflecting a profound lack of understanding of the extension mission that variety testing serves. University administrators had entirely lost sight of the fact that extension variety testing was established as a service to farmers, not a means to provide industry sponsors with proprietary data on their varieties at their behest. These changes meant that partial indirect costs and full fringe benefits were now taken out of these fees, decreasing their purchasing power dramatically. On the royalty side, University policy had initially allowed 90% of royalty income to flow directly back to support breeding programs at Cornell. This policy was changed to where none of the royalty income was directed back to the breeding program. Rather, 2/3 of the income went to the technology office and to University and College administrative functions, and 1/3 was assigned to the breeder(s) personally. Breeders have the option to donate their royalty income back to the breeding program, but also then have to personally cover the income tax obligations associated with that income. Aside from the highly questionable ethics of compensating an employee personally, beyond their full time salary, from the job they are assigned and paid to do, this again cut into funds that had been available to support breeding programs.

In the wake of all these changes and losses came sequestration, which chopped away at real Hatch dollars. On top of that has come the tendency of Cornell (along with most of its sister institutions) to "save money" by distributing administrative tasks back onto the shoulders of the faculty and technicians who are trying to manage breeding programs, thus cutting deeply into their time. This entire history has left breeding programs relying predominantly on grants, check-offs, and special projects for the entire cost of running a breeding program. Although most faculty members' salaries are still provided by core funds, their time is now dedicated largely to grant writing, reporting, and administrative tasks they have had to pick up, cutting into the time they have to devote to actually being plant breeders. The current mix of funding sources can help to maintain or expand a breeding program. However, these funding avenues are not available in all cases (e.g., some states and crops have no provision for check-off dollars, and grants and special projects may not be available for the particular crop or trait of interest), are unreliable (e.g., any given grant proposal or project often has a small chance of actually being funded), and they are short-term in nature (i.e., awards are typically for one to four year time periods). A mix based on these types of funding sources cannot possibly provide the long-term, continuous core funding that is essential to a successful breeding enterprise, and which can reasonably be supplemented by short-term and variable funds.

There have been some efforts in the field corn breeding area to address this challenge. The U.S. Germplasm Enhancement of Maize (GEM) project, for example, is a government-funded effort that was established with the help of private sector lobbying. Its goal is to "widen the germplasm base of commercial hybrid corn in the US through the introduction and incorporation of novel and useful germplasm gathered from around the globe." In its initial year (1995), it was funded with $500,000 that helped to support projects done by 15 public sector cooperators. Funding has grown and the GEM project is currently funded at $1.3 million annually, but public cooperator projects (which were still at 14 in 2004) have declined – in 2012 there were only four and in 2013 there were none. Hence the initial hope that the GEM project could help to rejuvenate public sector corn breeding programs has largely evaporated.

The U.S. Testing Network (USTN) represents another effort to bolster public sector and small private sector corn breeding, in this case by providing a more broad-based opportunity for variety evaluation. USTN has 27 public and private sector members who collectively did yield testing of corn varieties at 41 locations in 11 different states in 2012. Yield testing sites span a range of maturities and include both conventional and organic sites. This effort strengthens the ability of all member programs to rigorously evaluate their products. It mirrors (on a smaller scale) the advantages that large multinational companies have by providing the opportunity to test across a much broader range of geographies without each program having to establish its own independent testing effort across that entire range. At present, however, it is not clear whether the fee structure of the USTN can continue to support the coordination and management costs of the network, so its future existence is far from guaranteed.

Even with these fairly high profile efforts to support public sector breeding of field corn, which is a major commodity crop, the prospects looking forward seem dim. For crops that are not major commodities, the future may look even more challenging.

Some steps that are needed to rejuvenate and maintain strong public sector breeding programs, for corn and other crops, include a combination of the things highlighted by this and my colleagues' presentations:

Commodity and industry support in the form of check-offs, scholarships, and grants, but also in the form of lobbying with policy-makers that highlights the important and unique contributions that can be made by public sector plant breeding.

- Strengthened capacity funds for long-term core support, upon which breeders can really build a program and a portfolio of funding. This would fund the "arc of research" that Carter et al. describe in their paper. The National Board suggested by Brown in his commentary might be one means of administering such funds. Other options could be considered, but clearly careful thought needs to be given to a mechanism for structuring, allocating, and maintaining accountability for such funds.

- Administrative re-evaluation of university policies affecting extension variety testing fees, royalty distribution and intellectual property, and "centralization" of administrative tasks when that actually equates to distribution of those tasks onto the shoulders of individual faculty members.
- Encouraging policy-makers and administrators to tackle these issues is challenging, but essential to the future viability of public sector breeding programs.

Response to ***"What is the State of Public Cultivar Development?"*** by Charles Brown

RESPONSE TO "WHAT IS THE STATE OF PUBLIC CULTIVAR DEVELOPMENT?"

Carter, Tracy, Sinclair, Isleib, Joost

Charles Brown[8]

Thank you for the opportunity to respond to this important paper.

Due to time limitations, I will concentrate mostly on corn breeding as seen through the lens of a small-medium sized seed enterprise (SME).

The focus will include trends in corn breeding, corn production, and some suggestions for a healthy breeding system.

Carter et al describe two breeding approaches, 'pipeline breeding' and 'arc of breeding' and suggest pipeline breeding is used by private breeding programs and arc of breeding is used by public breeding programs due to factors inherent in each approach.

The achievements of pipeline breeding have resulted in ever higher corn yields over the past five decades have been nothing short of amazing. The private breeding efforts and their annual increase in bushels per acre has been the quiet backbone of our civilization. However, it is fair to say that their accomplishments would not have been possible without the solid foundation laid by the public universities in source germplasm and trained breeders to improve the materials. Without A632, B73, Oh43, Oh7, Mo17, W64A to name but a few, it is arguable that we would not be the world leader in corn germplasm. Much of the paper illustrates the shift in breeding resources from public to private control. This is not to say that there needs to be a quantum shift of breeding resources back to the public sector, there is no need for the public sector to compete directly with the private sector. However, there is a need to shore up some of the resulting weaknesses of 'pipeline breeding', available product choices and the current lack of supply of future trained breeders.

Trends

Regarding corn genetics, what are the "new, not resolved and not well understood" problems (paragraph 3) that Carter et al refer to?

There is an undisputable fact that corn production as an aggregate currently exhibits much higher disease expression than in the 1970's, 1980's and 1990's. Two trends in breeding approach utilized by the private breeding programs are 'die and dry' and limited genetic

[8] President Brownseed Genetics

diversity which have contributed to this.

Die and dry

Whole plant moisture is a function of the maturation process in corn. The use of disease to shorten the maturity of corn hybrids to allow the yield potential of later maturity hybrids to be moved earlier is widely used. This manipulation has been mitigated by widespread use of fungicides, which now is mandatory in a best practice breeding and crop production program. The results of this breeding approach may be monitored by evaluating test weight of harvested grain, which would be affected by early shut-down of the plant. In recent history we have not seen a high correlation of disease expression to reduction of test weight, however at the same time, we have not had the widespread environmental conditions to setup accelerated disease progression. What will be the result if we have a year with 'perfect storm' environmental factors for aggressive and early on-set of corn pathogens? Or the result, if we do not find fungicides that effectively protect the plant from ever-mutating pathogens? It is notable that recent fungicide products have two modes of action instead of just one, suggesting the fungicides are evolving.

The decisions made by private companies towards their breeding apply to nearly all of our corn acres planted in the US, and these occur in a private, non-public forum. They are not open for discussion and in the case of 'die and dry' if not currently available, a peer reviewed study on the benefits and risks would be valuable. Should the risks be unacceptable of die and dry, an 'arc of breeding' approach as suggested by Carter el al with public corn breeding programs could supply alternative options for private breeding programs with germplasm containing more plant health.

Genetic diversity

The fact that there are very few inbred family backgrounds utilized in the majority of corn production is not new. Today, from observation, there seems to be over-riding use of the BSSS x IODENT heterotic pattern. Inherent to the pipeline approach, the lines are recoveries of recoveries of recoveries, etc. This has been a factor in the yield gains and the disease susceptibility as described above.

Genetic diversity presently is also complicated by the fact that in the past, we referred to genetic diversity as the genetic distance of genes from each other in the corn genome. Now, with the use of transgenes, there are new genes to consider, especially the promoter genes, which 'switch on' transgenic traits introduced into the new host. In the past, there was only one promoter used in transgenic products, for both corn and soybean, namely 35s. Now, I am told there are other promoters used, thereby broadening the 'genetic diversity' of the transgenic promoters, which would be a good thing. And perhaps the concept of promoter genes being a commonality in corn and soybeans and thus subjecting them to disease susceptibility is open for debate. However, the decisions of what promoters to use and how widespread to use them and their implications are made in private, not subject to public debate or knowledge. We simply don't know.

Perhaps this is not a concern, however, being one who lived through the *Bipolaris maydis* (southern corn leaf blight) disaster of 1970, where one commonality in corn, namely T cytoplasm, was widely used and susceptible to southern corn leaf blight, caused us to lose 30% of our corn crop in 60 days. This suggests it is something to think about. We hope the right path is being followed, but the pressures of capital markets may direct the ultimate outcomes. Is our corn crop on 'life-support' comprised of ever more vulnerable plants that require propping up for maximum yield, or is there nothing for concern? Who knows?

Trend in corn production

In the past, if growers did not need a crop input, they could choose not to use it. However presently, this has changed due to the types of seed products made available to growers. One has only to review seed catalogs to see how many products are available that offer alternatives from multiple stacked modes of action for herbicide and insect resistance. These are positioned in the market as 'insurance' and built-in to seed products, all of which are part of the ever higher cost of seed. This forces growers to purchase trait protection they may or may not need, invest more in the cost of production and ironically, add risk to their profitability in volatile grain markets. If there were more publically available alternatives developed in a robust public breeding system, from an economic standpoint, growers would have alternative options and potentially less cost of production resulting in more profit at the farm level. These are some of the reasons currently acted upon and resulting in the exemplary support of the United Soybean Board to public soybean research.

Suggestions for a healthy breeding system

Establish a National Board: by crop

If not already in place, there needs to be an advisory board to provide a national agenda and public forum for debate of issues regarding each crop's needs in a science-based peer reviewed environment, sans personal agendas of the public or private sectors. In addition, it would function to advise the crop's breeding efforts, both public and private. Recommendations for funding of grants after thorough vetting, and showing accountability of the results would be included in such a board's duties.

Another function of such a board's national agenda would be advise the University system as universities begin to work together in order to coordinate their infrastructures and reduce redundancies, so to unleash a new level of performance. For example if a university has a breeding program with 30,000 plots, and a private program may have 100,000 plots, by coordinating infrastructure of field testing of three Universities their breeding program is now competitive as far as plot resources, while at the same time a training ground for new breeders.

We need a new environment of public/private cooperation with the goal to develop the crop as a national resource. Membership would have to represent what the public and private breeding programs have to offer to create a best in class model of cooperation. I do not think this would damage the market shares of individual private seed companies, due to the fact that that is based on relationships at the farm gate. This cooperation would bring the public breeding programs back to a level of sustainability and improve the future for us all.

What comes to mind is a type of NOSB, which is an advisory board for USDA's NOP, or AOSCA, which is an association of all Crop Improvement Associations.

Specific Public Funding Needs:

-Establish dedicated funding schemes for whole plant physiology research to universities able to deliver the genetics and training for future breeders. Assure it is adequate in amount of funds and length of years.

-Establish robust graduate training and internship programs with the private breeding companies.

Implement 'pipeline breeding' to the public breeding system so to accelerate products to industry royalty revenue stream.

-Direct portion of revenues generated from university royalties back to the department and to researchers and breeders so to directly benefit from their efforts.

-Provide the breeder with enough funds and time to accomplish their job. Reduce the need for non-breeding activities as much as possible.

-Universities cooperate with other universities with a national agenda of furthering the crop. Increase field testing to multi-state level by sharing infrastructure, materials, methods, bioinformatics.

-Fully fund GRIN, Germplasm Resource Information Network, to refresh germplasm stocks, and provide legal support to assure freedom to operate to receivers of GRIN materials. GRIN is the primary source of competitive germplasm for independent SME breeding programs in the US. Bar none.

-Fully fund Competence Center for Doubled Haploid Research under direction of Thomas Lubberstadt, Iowa State University and Martin Bohn, University of Illinois. Their letter of intent has been accepted by

National Science Foundation. This would allow independent SME breeders the latest double-haploid capabilities to compete in the ever constant race to find new combinations of genes.

-Support the efforts of National Germplasm Resource Advisory Committee (NGRAC) to manage our national germplasm collection.

Farmer Commodity Support:

-Create an entity in the corn industry to follow the soybean model of the United Soybean Board as a major form of support to the public breeding efforts.

In Conclusion

The public breeding of US crops is at an unsustainable level, in fact with corn, it has collapsed from former efforts. We need to be stewards of our germplasm resources just as we are of our land and water. The public and private sectors must work together to create and maintain public plant breeding. Carter et al have raised a warning with this important and timely paper and hopefully we can read the writing on the wall before our backs are up against it. It is time to act, and set in motion activities that provide for a healthy public breeding system to provide products for the long-term and provide training for future breeders.

If not us, who? If not now, when?

Response to ***"What is the State of Public Cultivar Development?"*** by Steve Diercks

RESPONSE TO "WHAT IS THE STATE OF PUBLIC CULTIVAR DEVELOPMENT?"

Carter, Tracy, Sinclair, Isleib, Joost

Steve Diercks [9]

I would like to thank Bill Tracy for the invitation to this conference and the opportunity to address this very important subject.

I am a potato, grain and vegetable grower from the central sands area in Wisconsin. All the crops that we grow are irrigated. I will focus most of my comments potato breeding.

The state of potato breeding in Wisconsin and across the United States has historically been done by public breeding programs. One might question the success of these programs in that the major variety grown, Russet Burbank, is over one hundred old. Does that mean that the breeding programs have failed or does it mean that something is missing in getting new varieties to commercial growers and ultimately to the consumers? Can public breeding programs train future breeders and also develop varieties which can be used by their grower communities?

As stated above, most of the potato breeding in North America has been done by public breeding programs with the exception of the short lived, New Leaf potato, developed by Monsanto in the 1990's and Frito Lays breeding program. A somewhat different approach has evolved in Europe where most of the new varieties are coming from private breeders. The European growers grow many more different varieties than their counterparts here in the US. Potatoes are sold in Europe by variety, much like apples here, while we are basically selling them by outward appearance, Red, White, Russet and Yellow. There has been an attempt by some growers to market by variety but it has not gained much traction yet.

As I look back on the potato breeding in Wisconsin over the past 40 years I have seen many changes. The program under Dr. Stan Peloquin was known for the many plant breeders that came out of his programs. Dr. Peloquin along with Don Kichefski selected a chip potato variety, Snowden, in the late 1970's and named it in 1990. This variety became the standard to which all chip varieties are still compared to. During the 1980's this variety was kept alive by a small group of seed growers who saw the potential of the variety. The irony of this variety is that by the time it was named in 1990 it was not placed under plant variety protection. The royalties that could have been collected from this

[9] President, Coloma Farms Inc.

one variety could have help to fund the breeding years for years.

The Wisconsin Potato and Vegetable Association, WPVGA, has supported potato breeders for over 30 years with funds obtained by a grower check off from all the potato growers in the state. Over 40% of the research budget, $350,000 in 2013, goes to breeding related projects. The hope is that this investment will lead to new varieties that will be more sustainable and create new markets for the growing community. To try to connect the plant breeders and the growers in the state a committee was formed call Spud Pro. This group which included representation from fresh market growers, chip growers, frozen process growers, potato processors and seed growers. This committee meets to evaluate advanced clones and recommend which clones should be moved ahead for plant protection.

Much like Spud Pro the United State Potato Board, USPB, has launched similar programs looking to fast track promising new clones from around the country for the potato chip industry and the frozen french fry industry. Both these groups have brought together breeders, seed growers, commercial growers and processors to streamline the introduction of new varieties to solve problems facing their sector of the industry.

The future of public potato breeding and what and how should be funded in my opinion are as follows:

-Continued support by USDA-ARS of the Potato Genebank at Peninsular Agriculture Research Station in Sturgeon Bay, WI to preserve genetic diversity for breeders.

-Continued support by USDA-ARS of potato breeders, plant physiologists, at both the state and national level.

-Increase connections with all phases of the potato industry to better understand their needs.

-Work with state grower groups to leverage their funds to fund state programs.

-Coordinate within growing regions with other breeders to accelerate new variety releases.

-Further refine or change the way dollars are returned to the breeding programs as successful varieties are released.

-Provide some incentive through licensing agreements so that seed growers and commercial growers in the state where the release took place to have the opportunity to first chance at growing and marketing new releases.

-With reduction in funding at both the state and federal level for all types of breeding programs it will be necessary for both state and national grower groups to continue or increase funding so these position remain viable.

Response Paper: A Clear Path Towards Breeding for a More Sustainable Agriculture by Adrienne Shelton

A CLEAR PATH TOWARDS BREEDING FOR A MORE SUSTAINABLE AGRICULTURE

Carter, Tracy, Sinclair, Isleib, Joost

Adrienne Shelton[10]

I love working in agriculture for a number of reasons, put perhaps most compelling for me is that farming is ultimately grounded in place. Each farmer is situated on a specific piece of land, identifiable by an exact set of GPS coordinates. Yet despite this rootedness, both the fields and the farmer are influenced by the surrounding interactions of geography, climate, economics, politics and culture. A farmer's choice of what to plant on her land is not nearly as simple as picking varieties out of a seed catalog, but is informed by all of the complex interactions within which she operates. Agriculture constantly challenges us to work within these opposing forces of stability and fluidity. Of course, the plants on which agriculture depends have mastered this art, evolving an amazing array of adaptations to withstand environmental changes while remaining firmly rooted in the soil. We still have much to learn from these remarkable organisms.

The dialogue of sustainable agriculture

Perhaps the most important contribution of sustainable agriculture has been in creating a public discourse in which both of these aspects of agriculture are considered. No longer can we assess an acre of land simply by the number of bushels it yields, but we also must consider the greenhouse gasses emitted in the process, the quality of its soil and water, the surrounding wildlife habitat, the economic viability of those farming the land, and the diet of those consuming its products. These dynamics have always been present, but we are finally beginning to talk about them as crucial aspects of farming.

Sustainable agriculture has many different definitions depending on whom you talk to, and this has led to frustrations with the term. For some farmers, sustainable may represent another set of regulations that must be abided by, each one chipping away at already slim profit margins. Others might view the term as a marketing tool, doing nothing more than helping consumers feel good about the products they purchase. I prefer the following definition of sustainability, proposed by Wackernagel and Rees (1996): sustainability "means living in material comfort and peacefully

[10] Department of Agronomy, University of Wisconsin – Madison (aschelton@wisc.edu)

with each another within the means of nature." Keeping this broad perspective in mind, one can return to the farmer's field where the concept of sustainable agriculture now becomes a specific set of achievable processes. What is sustainable for a Wisconsin dairy producer may look very different from a lettuce grower in the Salinas valley of California, or a diversified vegetable farmer in upstate New York, but it now also can look very real. This way of thinking is a remarkably different approach from the one-size-fits-all theory that has been the model for industrial agriculture.

Current state of plant breeding

As breeders, we have an opportunity to contribute to a more sustainable agriculture, and the way forward is very clear: we need more breeders working to develop locally adapted cultivars for regional farm and food systems. Unfortunately, the current distribution of plant breeders today does not lend itself to this model of breeding. While formal studies such as Frey's (1996) report on the distribution of public and private plant breeders and Fuglie and Walker's (2001) economic analysis of resource allocation by crop have not been updated for well over a decade, the trends they observed do not appear to be changing. Private breeders greatly outnumber public breeders actively engaged in cultivar development, with investment dollars mainly spent on the highest market value crops such as corn, cotton and soybeans. Consolidation within the seed industry means that few regional seed companies remain to serve the unique needs of growers in their area (Hubbard 2009). The largest seed companies spend upwards of $1 billion a year on research to develop new varieties that ensure the continuation of the current industrial model of agriculture ("Monsanto: The Parable of the Sower" 2009). We need alternative models, which surely will not arise from those heavily invested in the status quo.

A clear path forward

So how do we go about changing the system? We must encourage and financially support current public breeders at Land Grant Universities to dedicate a portion of their work to cultivar development. Through resources such as colleagues working in agricultural extension, public breeders are ideally situated to understand the social, economic, and political context in which farmers in their region operate. Agricultural experiment stations enable breeders to develop cultivars that are adapted to regional soils and climate. This model is not new, but it is no longer common. A great example of the effectiveness of this approach comes from Wisconsin, where breeders at the University developed short season corn hybrids from the 1930s-1960s to better serve farmers located in the northern tier of the state (Crabb 1992).

By developing regionally adapted cultivars that enhance sustainable farming systems, public breeders are not only able to provide an important service to farmers. Such breeding efforts also enable unique collaborations with regional seed companies. Building a robust breeding program is costly and creates a barrier to entry for companies wanting to gain a foothold in the seed industry (Fernandez-Cornejo 2004). By partnering with public breeding programs, regional seed companies can commercialize and distribute varieties developed by public breeders, returning a royalty on seed sales to help support public breeding programs. High Mowing Organic Seeds, a small seed company that sells 100% organic varieties, has done just that. After trialing a number of inbred sweet corn lines developed at the University of Wisconsin – Madison on their farm in northern Vermont, High Mowing has produced two hybrid sweet corn varieties that are being sold commercially and returning royalties to the UW – Madison sweet corn breeding program.

Finally, public breeders play a critical role as the trainers of the next generation of plant breeders. As a graduate student, I cannot stress enough the value of working with a breeder who is actively developing useful cultivars for farmers' fields. Through my involvement in Dr. Tracy's sweet corn breeding program, I have learned the value of selecting quality germplasm to be used as parent material, the importance of open access to diverse and unique populations for continued cultivar improvement, the necessity of a keen and honest eye in sorting the good progeny from the bad, and the synergy that can emerge from collaborations across public, private, and non- profit boundaries. In developing new sweet corn populations for organic growers, I have had the opportunity to take what I have learned in class lectures and from observing Dr. Tracy at work, and put them into practice.

There is no question that we need a more sustainable food system. Public breeders are well situated to contribute to this new agriculture. The infrastructure is already in place. Entrepreneurs are ready to assist in the distribution of publicly bred varieties. Graduate students are enthusiastic to participate, as indicated by events such as the Student Organic Seed Symposium (Luby, Lyon, and Shelton 2013). What we desperately require is public funding to turn this vision into reality.

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Keynote Paper # 2: "What *Would* 21st Century Breeding Programs look like if Breeding Programs were Geared to Sustainable Agriculture"?

Author: Margaret Mellon

What *Would* 21st Century Breeding Programs look like if Breeding Programs were Geared to Sustainable Agriculture?

A Concept Paper

Margaret Mellon[11]

What *would* 21st Century breeding programs look like if breeding programs were geared to sustainable agriculture? This is great question, but a complicated one for a couple of reasons. To begin, there is some confusion inherent in the question. Are we asking how to design plant and animal breeding programs to support existing sustainable agricultural systems or somehow to generate them? Being clear about this is important because much of our current agriculture is not sustainable and plant and animal breeding is not by itself capable of making it so. In addition, what do we mean by sustainable agriculture? As always, sustainability is a sprawling concept difficult to pin down in practical terms.

A comprehensive response to this question would tackle the definition of sustainability, which is beyond the scope of this paper. Nevertheless, I would like to put out few ideas that might be useful in structuring the conversation. I suggest that for crop and animal breeding programs to be successfully geared to sustainable agriculture in this century, they should:

-Be embedded in agricultural systems designed to address the major problems of the 21st century.

-Be based on a robust network of publicly supported classical plant and animal breeders.

-Initially support the areas of agriculture that are already headed in a sustainable direction.

-Be organized into regional centers working on agendas established in cooperation with local farmers.

Each of these ideas is discussed below.

I. A 21st century breeding program geared toward sustainable agriculture should be embedded in agricultural systems designed to address the two major threats to U.S. agriculture.

A sustainable agriculture in the 21st century needs to respond to two broad existential challenges—climate change and the cumulative impacts of decades of environmentally abusive agricultural practices.

Climate change for the most part is an external threat to agriculture manifesting itself in intense regional weather extremes like droughts, torrential rains, and prolonged heat waves. U.S. agriculture is highly vulnerable to the stresses

[11] Science Policy Consultant

represented by these weather events because it rests on a narrow genetic base of relatively few varieties of a relatively few crops.

By contrast, the impacts of abusive agricultural practices emanate from within agriculture and include extensive water and air pollution, soil degradation and an imbalanced nitrogen cycle. The damage, which is cumulative, results from a relentless focus on agricultural productivity leading to excessive dependence on chemical pesticides and fertilizers. Whatever the definition of sustainability one chooses; these impacts are inimical to it. To move toward sustainability, agriculture must transition into new systems that does less damage to the both environment and the long term viability of agriculture.

To respond to these twin threats, US agriculture needs to be reoriented to achieve environmental goals without sacrificing productivity. The problems of climate change and environmentally destructive agriculture are complicated—and interrelated—and there are many ways that one could articulate goals that would respond to them. In line with the description of the problems above, I suggest referring to the new goals as resilience and environmental balance.

Both of the goals are imperfect.

Resilience is a coping strategy not a a solution to climate change and in that regard is ultimately unsatisfying. But we are past the stage of avoiding climate change. And there are practical ways to minimize the impact of weather extremes on agriculture at farm, regional or national levels.

Individual farms, for example, can be made more resilient by growing a greater variety of crops, choosing hardier crops, or enriching soil quality and ability of soil to retain water. Nationally or regionally, a patchwork of cropping systems and farm types can act as a structural hedge against the unpredictable weather extremes. Different farms and crops are likely to be differentially susceptible to stress. Encouraging diverse farms across regions can help makes U.S. agriculture as a whole resilient to weather extremes.

Like resilience, environmental balance in agriculture is a malleable and elusive target hard to reduce to specifics. That being said, the path to ecological balance is well understood. The key is to approach agriculture as a managed ecological system and use a deep understanding of the relationships of elements within the ecosystem (including the surrounding landscapes) to *simultaneously* achieve high productivity and environmental goals like stress tolerance and weed and insect control.

Like many cutting edge technologies, agro-ecological approaches depend on sophisticated knowledge, observational skills and systems management. While agroecology has already produced impressive results, the full potential of such systems is only beginning to be appreciated.

It is fortunate that the same agro-ecological approaches that produce environmental balance in agriculture also produce resilience in the face of change. We know the lodestar to follow in both cases: increase diversity—at every level—more kinds of crops, more crop varieties in more kinds of systems. Understanding the strategic role of diversity allows us to cut through the complexity of the problems and the fuzziness of the goals and move toward solutions.

But as important as plant and animal breeding are, breeding programs cannot respond to challenges of the 21st century in a vacuum. To be effective, breeding programs must be integrated into farming systems and communities of farmers. And those systems must be *designed* to be resilient, environmentally balanced and sustainable. And they must be economically feasible for farmers to adopt.

II. A 21st century breeding program geared to sustainable agriculture should be based on a robust network of publicly supported classical plant and animal breeders.

The infusion of diversity into agriculture demands new breeding programs capable of delivering a steady stream of crops and animals to keep up with a constantly evolving agricultural, natural, and—for that matter commercial—environments. The program must be able to insure a wide variety of crops at reasonable cost. A robust public system based on classical plant and animal breeding is the best way to achieve that goal.

Classical plant and animal breeding is the only crop improvement technology that is both powerful enough to generate a plethora of new varieties of plants and animals and cost effective.

Classical plant and animal breeding have proved their worth over decades. In crop after crop they have delivered the multi-gene traits essential to agriculture like intrinsic yield, drought tolerance, pest resistance, nitrogen use efficiency. The US agricultural juggernaut is a testament to their power. Just as importantly, classical breeding is cost effective. It can develop new seed varieties inexpensively enough to offer crops, cover crops and forages for many situations, for example, crops with planting dates that fit into crop rotations.

Molecular crop improvement technologies, like genetic engineering (GE), were once expected to open new vistas in plant and animal breeding and perhaps supplant classical breeding. Instead, after 25 years of trying, genetic engineers have had only limited success, primarily with crops able to withstand herbicides. Genetic engineers apparently have not been able to overcome the technical barriers encountered when trying to confer multi-gene traits and have found only a handful of useful single genes. Although there are sporadic reports of discoveries of new multi-gene traits, few have been approved for commercialization. So far there no commercial varieties claiming key traits of increased intrinsic yield or water use efficiency.

The wide adoption of the herbicide-tolerance and insect resistance traits in corn and soy provided a burst of commercial success that has masked how far the GE crops have fallen short of early hopes. The reasonable expectation that eventually genetic engineers would eventually overcome technical barriers has been fading as decades have gone by and herbicide-tolerance remains by far the highest acreage application of genetic engineering.

Doug Gurian-Sherman of the Union of Concerned Scientists has produced a trilogy of reports carefully analyzing the performance of transgenic technology and evaluating the prospects for the technology in the future. As Dr. Gurian-Sherman has shown, the accomplishments of the herbicide-tolerant and BT crops, although real, are modest. Perhaps as a way of compensating for lack of success, biotechnology advocates often brazenly take credit for yield increase in corn and soy resulting from classical breeding rather than engineered traits. Even the success GE crops currently enjoy is tempered by the predictable emergence of resistant weeds and insects.

But even at its best, GE's benefits in cropping systems in no way compare to the stunning contributions of classical breeding to agriculture.

In addition to having a disappointing track record, transgenic technologies are expensive, which undermines their utility in developing sufficient numbers of products to support a diverse agriculture.

Other molecular technologies like marker assisted selection can in some instances enhance the effectiveness of classical breeding and may have a place in programs where they lead to finished cultivars. But marker assisted selection needs to be carefully evaluated as a part of breeding programs. It, too, can be expensive and could consume resources better devoted to more cost effective classical breeding.

In sum, diversity is the core feature of an adequate respond to the challenges of the 21st century agriculture and classical plant and animal breeding is by far the best technology for delivering that diversity.

III. A 21st century breeding programs geared to sustainable agriculture initially should support the sectors of agriculture that are already headed in a sustainable direction.

Adequately supported, classical breeding can help unlock the untapped potential in plants and animals needed to adapt to climate change and develop regional agricultures. But, as mentioned above, new agricultural systems are required if U.S. agriculture is to become sustainable. To transition to those systems, we need to understand why the current system is so successful. One reason is that It aligns individual farmer's near-term economic interests with the national policy goal: productivity increases famers' bottom lines as well as producing inexpensive food and feed and bolstering trade.

A broader and more comprehensive, agricultural system program would preserve productivity as a central goal while expanding the programs to take on the environmental balance. But expanding the goals of agriculture to include environmental goals faces a major challenge. Unlike productivity, resilience and balance are diffuse and multifaceted goals. They are difficult to define and monitor. In addition—and this is very important—achieving environmental goals does not necessarily increase farmers' near-term profits.

A new breeding system aimed at simultaneously achieving environmental and productivity goals—although in both farmers' and the country's long term interests—will not necessarily align with farmers' near-term economic interests. This is especially true in conventional row crops systems. In so far as it doesn't, a plant breeding program committed to sustainability and resilience will be offering a product many farmers may not want.

Of course, not all agriculture is stuck in the old industrial paradigm. There are emerging areas of agriculture that are employing sophisticated new approaches to agriculture based on agricultural diversity. And they are proving themselves to be economically viable. These systems represent the fruit of ongoing collaboration between a new generation of consumers and forward thinking farmers. The consumers are searching for health, flavor and meaning in food. The farmers are responding with organic, sustainable, and local and regional agriculture—and prospering.

These emerging farm sectors embody systems that rely on agronomic diversity to maintain productivity with less reliance on chemicals and increasing soil quality. Producers in these sectors are eager to work closely with breeders to develop seeds and animals that can be grown organically, sustainably or regionally. These agricultural pioneers are already succeeding in the marketplace with systems that achieve multiple goals and making progress toward resilience and environmental balance. Since their economic interests are already aligned with the the goals of a transformed agriculture, these are the sectors of agriculture to which new plant and animal breeding resources should be directed.

While continuing to bolster the sustainable sectors of agriculture, policymakers must also initiate efforts to transform sectors of agriculture, especially row crop agriculture, where farmers' economic interests are not currently aligned with climate and sustainability goals. That will take new policies and incentives to make the desired systems economically feasible. One way to go about it would be to establish diversity goals in row crops, perhaps via requirements for crop rotation or rewards for good practices ala the Conservation Stewardship Program. However it is done, the system has to be practical and not ask farmers to sacrifice economic well-being for future environmental benefits.

Under a redesigned system, row crop farmers would begin to demand the services of a reoriented classical plant breeding establishment. Obviously, this is a huge undertaking that would eventually loop back to the way we do animal agriculture.

We cannot wait for this policy transformation to get going on a new breeding program. We should establish one right away to buttress the growing sectors of agriculture that already embody diversity in agriculture. The successes growing out the increasingly close collaboration between organic, sustainable and regional farmers and classical breeders could become part of the argument for changing mainstream agriculture.

IV. A 21st century breeding programs geared to sustainable agriculture should be implemented through regional centers working on agendas set with farmers.

The mission of the 21st breeding program—the support of an increasingly diverse agriculture designed to be resilient and environmentally balanced—is ambitious and faces many challenges in implementation.

For example, there are many options for more sustainable agricultural systems in the US, among them: 1) systems based on perennial grain crops; 2) integrated mixed crop and animal systems; and 3) annual cropping systems that incorporate rotations and cover crops.

Classical plant and animals breeders are vital to enable and support any of these systems, but would need to operate within a national mission. Although the broad outlines of the mission would be established at the national level, many decisions will be made within farmer-breeder collaborations. To implement such a mission, plant and animal breeders must be deployed so that they can work in close collaboration with farmers to develop finished cultivars that fit into resilient and environmentally balanced systems.

The best way to facilitate those farmer-breeder relationships is by deploying breeders in regional centers around the country where they can to establish long term relationships with farmers. Decisions about which kinds of animals or cultivars to develop would be driven by determinations of what farmers want to grow and think they can sell. The centers would have sufficient staffing and resources to produce finished cultivars tailored to local conditions and markets.

Part of the implementation challenge is to monitor progress on diffuse environmental goals and adjust activities over time. Setting up benchmarks and monitoring systems will require input from other scientific and agronomic disciplines. But it is useful to remember that the acreage of organic, sustainable and regional systems is itself a metric for reaching environmental goals in agriculture because those systems generate geographic and crop diversity essential to resilience and afro-ecosystems.

In Conclusion

21st century breeding programs geared to sustainable agriculture would be embedded in agricultural systems that respond to the twin existential challenges of climate change and environmentally destructive practices. Such systems would implement agricultural policy reoriented around goals of resilience and environmental balance. Achieving those goals requires a constant stream of new plant and animal varieties to adapt to an ever changing environment and provide resources for agro-ecosystems. Classical plant and animal breeders would be uniquely qualified cost effectively to produce the needed crop and animal diversity if deployed to work in close collaboration with farmers. Successful establishment of vibrant classical breeding programs is essential to the capacity of 21st century agriculture to confront its unprecedented challenges.

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Response to ***"What Would 21st Century Breeding Programs Look Like if Breeding Programs were Geared to Sustainable Agriculture?"*** by Fred Kirschenman

FROM SOIL TO SUSTAINABILITY

Frederick Kirschenman[12]

"The subject of soil, plant, animal and human health is one great topic." -Sir Albert Howard, An Agriculture Testament

Defining Sustainability

As most everyone interested in sustainability knows by now, the concept has been appropriated by numerous entities and used in various ways, often to achieve different objectives. In his introductory chapter to the, excellent, 2013 edition of the Worldwatch Institute's State of the World report, Robert Engelman coined the term "*sustainababble*" to reflect this "*cacophonous profusion of uses of the word sustainable to mean anything from environmentally better to cool.*" Increasingly the term is used as a marketing tool, often it is used as an environmental metric, and, of course it is used extensively to describe an "*improved*" food and agriculture enterprise. While many of these uses may be grounded in good intentions, the result, as Engelman points out, has "a high cost." "*Frequent and inappropriate use lulls us into dreamy belief that all of us---and everything we do, everything we buy, everything we use---- are now able to go on forever, world without end, amen.*" (State of the World, 2013)

Such a "*dreamy belief*" has certainly been prevalent in most of the visions of contemporary "sustainable agriculture". Whether one belongs to the school of sustainable agriculture which is fixated on the notion that sustainability can only be achieved by intensifying the technology of our dominant industrial agriculture, or to the school of "*greening*" the system by inserting more environmentally friendly practices, or to the school that insists everyone must transition to organic, all are grounded in the belief that the fundamental principles of modern agriculture, which emerged in the early 20th century, can continue. According to this standard we simply need to tinker with the current system, in various ways, to make it "*sustainable.*" While such "*tinkering*" can sometimes produce positive, short-term, results, it fails to address the new challenges which will emerge in the near future. Occasionally pundits now refer to this "*dreamy belief*" of sustainability (appropriately, I think) as "*band aid sustainability*."

Historical Context

In his engaging book, Culture and Agriculture: An Ecological Introduction to Traditional and Modern Farming Systems, anthropologist, Ernest Schusky provides us with a summary of how the human species have fed themselves since they evolved on

[12] Distinguished Fellow, Leopold Center for Sustainable Agriculture, Iowa State University

planet earth some 200,000 years ago. I think such a historical context can help us to better frame the concept of sustainability. Schusky reminds us that for most of our time on the planet we fed ourselves as hunter gatherers. Like many other species we tended to live in small tribes, gather and hunt the food available in a particular place, until the food sources became depleted and then moved on to another place. Apparently various methods were also used to limit population growth to keep population density within "carrying capacity."

It wasn't until the Neolithic Revolution, approximately 10,000 years ago that we began to transition from "*food collectors*" to food producers by domesticating plants and animals. We began to live in settled societies, and attempted to produce enough food in place to feed a local, settled, population.

As Schusky points out, this new way of feeding ourselves was "*land intensive*." It tended to mine the natural fertility of the soil. Consequently, much of this early agriculture was based on "*swidden cultivation,*" also known as "*slash-and-burn*" agriculture. In other words, a common practice was to burn off perennial plants---trees or grasses---and then cultivate the soil, plant seeds (usually cereals)--- and the natural soil fertility plus the fertilizer from the ash initially produced good yields the first year. However yields would decline quickly, as natural soil fertility diminished, so the general practice was to slash-and-burn a new plot of ground every year or two, and allow the first to lay fallow for 15 or 20 years, before returning to cultivate it again, after soil fertility was restored.

In the mid-twentieth century we introduced a new form of agriculture, which Schusky calls the "*Neocaloric Revolution,*" since it is entirely dependent on "old calories"---fossil fuels, fertilizers, fossil water, etc. The discovery of fossil fuels was the principle innovation that ushered in the industrial revolution, but it wasn't until the mid-twentieth century that industrial methods were applied to agriculture on a large scale. (Schusky, 1989)

While Justus von Liebig came up with the idea of substituting synthetic fertilizers (Nitrogen, Phosphorus and Potassium) for the "*laborious*" practice of maintaining soil health, and Fritz Haber and Carl Bosch divised the means of making ammonia from atmospheric nitrogen in 1909, the adoption of this high input, industrial agriculture did not take place as the dominant form of agriculture until after World War II.

There were numerous agricultural visionaries, soil scientists and ecologists, who issued strong warnings that this "*N-P-K mentality*" (as Sir Albert Howard called it) was the wrong direction for agriculture since it was contrary to the workings of nature and was, in fact, a "*form of banditry*" since it would steal the availability of healthy soil from future generations. (Howard, 1943) F. H. King, Liberty Hyde Baily, Aldo Leopold, William Albrecht, Hans

Jenny, Wes Jackson and many others had similar concerns. They saw that maintaining the health of soil was crucial to any kind of truly sustainable food system. And they were all aware that the modern industrial agriculture was still extremely "*land intensive*" and therefore damaging to the health of the land, we simply substituted "old calorie" inputs in place of healthy soil.

Of course, the immediate short-term benefits of industrial agriculture---the maximum, efficient production for short-term economic return---were too compelling to seriously consider the warnings of such visionaries.

However, Schusky reminds us that the "neo-caloric era" will of necessity be a very short period of time in the time-line of human history. We sometimes forget that this "*modern*" agriculture is dependent on a collection of "old" (non-renewable) calories which we are rapidly using up. We also seem to forget that the first producing oil well in the US became operational in Titusville, Pennsylvania in 1859, (approximately 150 years ago) and it was fossil fuels (especially petroleum) that provided the cheap energy which sustained the entire industrial economy. But all of these old calories are stored, concentrated energy---- fossil fuels, rock phosphate, potash, fossil water, etc..---and these old calories had accumulated in the planet over many millennia. But once they are gone the neo-caloric era, according to Schusky, must end, and we will need to redesign a new agriculture that can be "*sustainable*" in the post-neo-caloric era.

The point to remember in all this is that unless someone finally finds a way to invent a perpetual motion machine, current, diffuse energy (sunlight) will never be as efficient (energy return on energy invested) as stored concentrated energy, consequently, any alternative energy we may invent in the future, will never be as "*cheap*" as fossil fuels have been.

In addition we need to acknowledge the ecological damage that the excessive use of the old calories has caused---damage that will further affect the "*sustainability*" of agriculture---more severe weather events due to climate change, eroded and degraded soils, depleted biodiversity and depleting fresh water resources. These are the "sustainability" challenges that will confront us in the decades ahead.

Of course, as the old calories get used up they will become increasingly expensive so the neo-caloric era will certainly end due to prohibitive costs long before all the calories are used up.

So, a good way, to frame the question of sustainability with respect to our future food and agriculture system is to ask ourselves if the current, industrial system (and any "*band aids*" we might apply) can still be "*sustained*" when crude oil is $350 a barrel, fertilizer costs are five times what they are today, we only have half the amount of fresh water currently available, we have twice the number of severe weather events, and our soils are even more degraded than they are today?

Anticipating the Future

Given the changes coming at us, a crucial challenge to sustaining a future food system will be to anticipate the changes and getting a head start preparing for them. Perhaps we can learn a critical lesson from the research conducted by Jared Diamond. Based on his intensive studies of past civilizations he concluded that those civilizations that anticipated the changes coming at them, recognized the value of their ecological reserves, and got a head start preparing for the changes, were the civilizations that tended to survive for the long term, (they were "*sustainable*") while those that failed in that exercise were the ones that tended to collapse. (Diamond, (2005) In this regard Schusky makes another important and sobering observation from his studies of human culture, namely, that "*humans manipulate their cultures to achieve many practical, short-range goals; what they do not foresee are many more long-term undesirable consequences. Innovations that solve immediate problems often have built-in effects that eventually will cause major problems.*" (Schusky, 1989) Perhaps these observations, from Diamond and Schusky, are among the most important to consider for anyone interested in achieving agricultural "*sustainability.*"

Given this scenario, it seems to me that the most urgent task before us now, is to do all we can to restore the biological health of our soils, before the remaining old calories become too expensive to be a viable resource for continuing to "sustain" our food system. Of course other issues will need to be addressed at the same time---crucial among them---putting a cap on carbon, restoring our biological and genetic diversity as much as possible, restoring as many perennials as possible (forests and grasslands), eliminating food waste, implementing the "*right to food*" and other recent UN proposals. (UN reports, 2008 – 2013) However, key to future food sustainability will be biologically healthy soil!

Beacons to Guide us

Fortunately we are not without practical wisdom to guide us as we design a new agriculture, for the post Neo-caloric era.

Here are a few "beacons" of light to guide us. I prefer to call them beacons, rather than "models" since we tend to think of models as examples that can be duplicated. In our new world we will need to pay much more attention to the uniqueness of each ecological "neighborhood" and design agricultural systems that are suited to each ecology, rather than imagining another uniform, homogenized, global agriculture typical of the agriculture which has evolved in the "neo-caloric era."

Here are a few of the "beacons" that can guide us on our future sustainability journey:

1. Deborah Koons Garcia, "The Symphony of Soil" This new documentary on soil is a masterpiece of science and art which can be used to transform the way our culture thinks about soil. No one can watch this video and still think that soil is just "dirt." It not only describes how soil was formed over many millennia, but also how to care for it and restore its biological health. The documentary can be obtained from Lily Films Inc.

2. NRCS and Cover crops. In recent months the Natural Resources Conservation Service, under the leadership of Ray Archuleta, has become very active, working with farmers and soil scientists to incorporate cover crops into their monoculture farming operations with significant results in beginning a process of restoring soil health. Farmers who have incorporated these practices for a period of 5 – 7 years have discovered that the improved soil health enables them to reduce their fertilizer and pesticide inputs by 70% and still maintain yields, furthermore the improved soil health dramatically improves soil moisture absorption capacity reducing flooding and nutrient pollution, as well as increasing drought tolerance. A video with some of the stories from farmers and soil scientists is available here: http://www.youtube.com/watch?v=nWXCLVCJWTU

3. The American Academy of Microbiology. "How Microbes Can Help Feed the World" One of the encouraging developments re. soil health in recent months has been the increasing attention given to the micro biome in soil. Even soil scientists a decade ago were referring to soil as simply "a material to hold a plant in place." Now we are beginning to understand that soil is a living community of organisms with billions of microbes at its base. While not perfect, a typical article on the subject has been published by the American Academy of Microbiology, "How Microbes Can help Feed the World," by Ann Reid and Shannon E. Greene, December 2012. It can be accessed by Googling the Academy.

4. John Deere, "The Furrow", February 2013. "Building Better Soils." I take further encouragement from the fact that John Deere elected to devote this entire issue of their "The Furrow" magazine to the subject of soil health. Again, many of the stories are about farmers and the benefits they have experienced from soil health restoring practices. Example, the magazine features Gabe Brown, a "20-year no-till, cover crop, and livestock" farmer near Bismarck, ND, who reports that before he started his soil health farming practices his soil was only able to "absorb a half-inch of water per hour. Now they'll take in 8 inches." This issue of "The Furrow" can be accessed at JohnDeere.com/Furrow.

5. Matthew Liebmann, agronomist at Iowa State University. Dr Liebmann has conducted over 10 years of research comparing results from typical two-year monoculture corn/soybean rotations, with 3-year rotations of corn/beans and small grain/clover, and 4-year rotations of corn/beans/small grain /alfalfa and a second year of alfalfa. The two year rotation relies entirely on synthetic inputs of fertilizers and pesticides and the 3 and four year rotations incorporate modest amounts of livestock manure. His research has demonstrated that the soil health improves in the 3 and 4 year rotations and fertilizer and pesticides applications can be decreased by almost 90% while return on investment in land and labor is slightly higher than in the two year rotation. Comparable ecological benefits have been demonstrated by incorporating perennial prairie strips into conventional corn/soybean monocultures. Reports on the published research can be obtained on the Leopold Center web site: http://www.leopold.iastate.edu.

6. The Land Institute. In Salina, Kansas, where Wes Jackson established a research and education institute to explore the possibility of developing perennial grains that could eventually replace annuals. After 30 years of research scientists have concluded that with additional research it could be possible to replace many annual grains, like wheat, sorghum, rice and other crops with perennial varieties. Perennial plants are much more resilient than annuals and have many soil building and carbon sequestration capabilities by virtue of their root systems. Scientists have already demonstrated the soil health restoration capacity of such perennial varieties. In the longer term, post neo-caloric, future, these new varieties are likely to become the core of sustainable grain agriculture. Information can be obtained on the Land Institute web site at www.landinstitute.org.

7. The importance and benefits of restoring biological health of soils are not only being recognized by farmers and agronomists, but also by economists and investors. In the April, 2011 issue of his widely read newsletter, Jeremy Grantham, one of the nation's leading investment counselors, reminded investors that it was "Time to Wake Up: the Days of Abundant Resources and Falling Prices are Over Forever." Grantham points out in this remarkable essay that investors need to change their investment strategies if they want to continue to make money on their money. Continuing to invest in cheap raw materials in order to increase value without paying attention to the natural and social capital which sustains our economies will not continue to be successful, and among other things he advises investors to "invest in soil." (Copy of the Newsletter can be obtained by Googling "Jeremy Grantham.") Woody Tasch, founder of the "Slow Money" investment movement and author of Slow Money: Inquiries Into the Nature of Slow Money: Investing as if Food, Farms and

Fertility Mattered, makes similar points about successful investing in the future and makes even more passionate appeals to "investing in soil health."

8. Restoring biodiversity and genetic diversity will be another critical goal in our post-neo-caloric future. Without all the "old calories" we will not be able to sustain the global, homogenized food system we have been cultivating. Consequently we will need to design a new food system that is properly adapted to each ecologically unique region of the world. To achieve that essential goal we will need to---as much as possible---restore the biodiversity and genetic diversity necessary to enable us to develop regional food systems appropriate to each ecological neighborhood. A crucial part of achieving that objective will be the restoration of a diversity of seeds and breeds that will enable us to produce diverse food systems appropriate to each ecology. In this task the excellent work of Gary Paul Nabhan in his book, Where Our Food Comes From: Retracing Nikolay Vavilov's Quest to End Famine, is an excellent resource to determine the challenges and opportunities related to that task.

9. Finally, health care professionals are beginning to recognize the relationship between soil health and human health, a connection that Sir Albert Howard had observed back in the 1940's. In his book The Soil and Health (1947) Howard suggested that we could not have human health without soil health, plant health and animal health, that are all "one great topic", and that this synergy would become the "health care system of the future." The connections between healthy soil, healthy agriculture and healthy humans is now reiterated by Dr Daphne Miller, a practicing physician and professor of family medicine. In her new book, Farmacology: What Innovative Family Farming Can Teach us About Health and Healing she provides numerous on-the-ground examples of such connections. Ronnie Neff, health care professional at the Johns Hopkins School of Public Health has also edited a book of essays suggesting the connections between healthy soil and human health, which will be published early in 2014.

Coda

One of the important lessons in all this that we might well pay attention to was articulated clearly by Wendell Berry in an essay that he published back in the 1970's, "Solving for Pattern." In that remarkable essay Wendell pointed out that in our culture we tend to try and solve problems in isolation, as if they were detached phenomena that could be solved with single tactic therapeutic interventions. But in fact problems are always part of a network of interrelated phenomena. Now, as long as we had all of the cheap "old calories" to perform the interventions, we could make the system work, but as we enter the post "neo-caloric era" at the same time that we have degraded the health of our ecological and social capital, we will need to begin recognizing the ecological complexity of living systems and the self-renewing capacity or our ecological capital (soil being a foundation of that capital), if we are to live healthy, productive lives, let alone feed ourselves, in our post neo-caloric future.

It is interesting to note that this shift in our thinking is now also being recognized by some of our leading economists. In a remarkable essay, published in the January/February, 2011 issue of the Harvard Business Review, Michael Porter and Mark Kramer suggested that businesses that wanted to be successful in our future could no longer operate by "the old playbook" of marginalizing labor and raw materials in the interest of adding value further up the supply chain, and neither could they continue to externalize social and natural capital in the interest of maximizing financial capital, since labor, raw materials, social and natural capital have now all been so compromised that we can no longer be successful in business unless we "share value" throughout each of these sectors of the economy. Isolated sectors of the economy can no longer be successful unless the whole economy is healthy. As they put it: "Shared value holds the key to unlocking the next wave of business innovation and growth. It will also reconnect company success and community success in ways that have been lost in an age of narrow management approaches, short-term thinking and deepening divides among society's institutions."

And healthy soil, lies at the base of all that shared value!

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Luncheon Keynote: "Taking the Long View: Changes over Time and What is the a Future Course?"

Author: Major M. Goodman

MAJOR GOODMAN directs the Department of Crop Science at North Carolina State University. The program focuses on the improvement of maize through the application of quantitative genetics theory and
the incorporation of exotic germplasm in traditional maize breeding. Goodman received a B.S. in Mathematics from Iowa State University, with a minor in Chemistry, and an M.S. and a Ph.D. in Genetics with a minor in Statistics at NCSU. Among his many accolades, he served as a member of the Rockefeller Maize Germplasm Committee in 1972-75, he served as three-fourths chair of the USDA Maize Crop Advisory Committee in 1981-86 and three-fourths chair on the advisory panel for Maize Genetics Stock Center in 1985-86.

Taking the Long View: Changes Over Time and What is a Future Course?

Major M. Goodman[13]

History

For much of the 20th Century, public breeding programs were active and important contributors to public and private varieties and hybrids. Comments will largely be limited to maize, but similar scenarios occurred with wheat, oats, alfalfa, cotton, soybean, sorghum, fruits, vegetables, etc. The decline in public breeding programs began in about 1965 when heavy promotion of molecular genetics gathered steam. The first crop that was supposed to see rapid improvement via molecular engineering (at that point mostly tissue culture variants) was to have been the potato. Peter Carlson, then of Michigan State, repeatedly said 'Within five years major advances in potato improvement will be achieved'. Indeed, "Within five years" was repeated so often over the following 30 years that the introduction of actual transgenic maize in 1996 was somewhat anticlimactic. Later Carlson said "All things seemed possible. For the first time, a good story was as important as performance… It's easier to weave dreams when you don't know the roadblocks ahead" (Charles, 2001). And the Russet Burbank, dating to 1914, remains the most popular U.S. potato variety (Schaeffer, 2011).

There was probably no deliberate federal (or state) decision to de-emphasize public plant breeding, but the growth and emphasis on NSF and NIH (and even USDA Competitive) Grants led universities to replace retirees in plant breeding (and other largely unfunded areas – have you tried to find a real herbarium taxonomist recently?) with new, grant-slinging molecular biologists who brought in overhead monies of around 50%. Many plant breeding grants – which are few and far between - bring in almost no overhead funds.

Other than the occasional teaching position, virtually no university hires are made in fields that are not fully self-supporting, and that was true even before today's current financial constraints. Public maize breeding is not generally self-supporting, even at an institution like Iowa State. The list of states that had strong public maize breeding programs in the 70s is immensely longer than the list today (Table 1) – and today's list is subject to near-term shrinkage (Tennessee and North Carolina, perhaps).

Similarly, there has been shrinkage of the number of private companies conducting maize breeding in the U.S. The big five, AgReliant, Dow, Monsanto, Pioneer, and Syngenta dominate, but several regional players (Becks, Stine, Wyffels, etc.) are important. In contrast, in the

[13] Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695

1970s over 350 maize companies competed (Norskog, 1995). Some were solely producers of hybrids licensed from foundation seed companies, such as AgAlumni Seed, Downing Foundation Seed, Illinois Foundation Seed, Holden's Foundation Seed, Mike Brayton Seed, Minnesota Foundation Seed, Ohio Foundation Seed, and later Thurston Genetics. Others did at least some of their own breeding, often combining their own lines with public or foundation-seed lines. Many had extensive breeding programs with several plant breeders each.

Grants

The logical source for grant funding for breeding has been the various USDA Competitive Grants programs. These programs have, from time to time, nominally funded research in genetic resources (and their use) and, on rare occasions, even applied plant breeding. However, the actual funding of proposals is largely dictated by panel membership and the USDA official in charge of the panel. My own experience has been (as an applicant, as a panel member, and as panel director) that applied breeding, regardless of need and quality, always loses out to molecular genetics, again regardless of need and quality. The only exceptions to this have been the specifically organic grants panels, which have yet to be hijacked by the molecular folks. But short-term grants, regardless of source, are not an intelligent way to fund the 15 year cycle typical of a real field breeding program.

Future

As Yogi Berra is alleged to have said, "The future ain't what it used to be" (Berra, 1998), and he is apparently not the first to have used that expression. I have no special insight on how private companies will maneuver. Until recently, Pioneer effectively controlled the germplasm (Mikel, 2006, 2011; Mikel and Dudley, 2006; Nelson et al., 2008); Monsanto pretty much controlled the transgenic traits (Leonard. 2009). I suspect that germplasm trumps traits. One can produce pretty good maize yields without traits, but assembling high yielding, agronomicly resilient hybrids takes years of breeding effort. In addition, there are almost certain to be weaknesses evident as "traits" are used ubiquitously around the world: the same structural gene, the same promoter, the same selective factor. This situation begs for a situation like the 1970s Southern Corn Leaf Blight epidemic.

But having said that Pioneer controlled the germplasm, everyone who legally could use Pioneer's germplasm. Some (but certainly not all) of those who used it illegally have suffered (United States Court of Appeals, 1994). And of course, everyone outside the organic community wants new (or new versions of old) traits.

The entire maize economy of the temperate world rests on derivatives of about a half-dozen lines (Goodman, et al., 2014): B37, B73, C103, Mo17, Oh7, Oh43, and PH207, all of which originated from public materials (although PH207 had a long history of development within Pioneer). Four of these are strictly male lines (C103, Mo17, Oh7, and Oh43). And they produce more of the same. B37 and B73 are females (as are their derivatives), while PH207 (Iodent) derivatives can sometimes be used as females, as can derivatives of A632, a once-popular, early B14-type. The concern over the narrowness of the germplasm base was the basis for the GEM (Germplasm Enhancement of Maize) Project and the excuse for the continued existence of North Carolina State's maize breeding project after better equipped, better funded, and probably better managed ones evaporated at Illinois, Iowa, Minnesota, Ohio, Purdue, and many others.

Funding of public maize breeding programs requires long term support. Grants programs are totally unsuitable; hence long-term program survival currently depends almost exclusively on direct state or USDA funding. While one would think it would be in the best interests of the Big Five to support strong public breeding programs – and a few have done so on rare occasions – but personnel changes at high levels within such companies make continual support unlikely. It is ironic that the widely-hated tobacco industry lavishly supports public tobacco breeding, but the largely-admired maize industry has restricted itself to a few short-term, small grants, usually for purposes of direct assistance to the companies themselves.

The Big Five all have international programs which should, in concept, make it easy for them to broaden the germplasm base of U.S. maize. Some have claimed to be doing so for many years. But the turnover of personnel involved with such efforts, the extreme pressure to produce new, better hybrids *now*, and the time investment required for work with exotic germplasm seem to combine to confound such efforts. In addition, there are germplasm protection differences between the U.S. and much of the rest of the world, where there is much more freedom to operate. (Selfing a competitor's hybrid is usually OK overseas, for example). But bringing derivatives of such materials to the U.S. (with possibly vague pedigrees) may have negative legal consequences. With closed pedigrees, it is sometimes not even clear whose ox is to be gored.

There are three widely discussed and apparently widely used genetic marker techniques that have captured the attention of both public and private breeding groups. (1) Association Analysis is essentially multivariate correlation analysis between markers and traits of interest across populations, adjusting, when possible, for population structure. (2) Marker Assisted Selection is basically within-population selection on markers associated with traits of interest. (3) Genomic Selection is selection on the basis of all markers showing favorable relationships to traits of interest, often regardless of the strengths of such relationships.

It is difficult to compare the costs and results of such efforts to the costs and rewards of customary field selection and testing. Goodman and Carson (2000) made such a comparison for field breeding with exotics as compared to transgenic breeding. With very conservative cost estimates for transgenics, the ratio was about 28 to 1 in favor of standard breeding procedures, even when using exotics (which are several times as expensive to work with as elite, adapted materials).

The costs of markers are rapidly dropping, and the new techniques are what newly minted PhDs have learned. Perhaps unfortunately, what is learned in graduate school is what they think they should do on the job. Appropriateness, likely outcomes, and maize's notorious genotype x year interactions are rarely considered carefully.

Consider the case for doubled haploids in maize. They do speed up the breeding cycle slightly, at considerable expense. The expense is not limited to direct financial costs, but includes lost opportunities to select for maturity, disease resistance, stress resilience, silk-tassel nick, etc. The procedure may be fine for derivatives of B73a x B73b. But even if there were no monetary costs, would it be very helpful for B73 x Tuxpeño? Doubled haploids are quite helpful for stacking transgenes – the real problem there is that there are so few to stack. Is the general utility of doubled haploids greater today than in the 1950s, when DeKalb tried and ultimately rejected them? Today's inducers are easier to use, and the frequency of haploids is higher, but has their utility increased in some way that is not obvious?

Markers function best with major genes. In maize, unlike wheat or soy, there are few, if any, major genes of consequence except transgenes. A lot of genes with small effects is the rule. Hence, how valuable marker techniques will ultimately be for maize in the long run is currently unknown. For the moment, the main value of markers in maize has been to shorten the backcrossing effort with transgenes and "finger-printing" lines and hybrids for quality control and ownership rights.

One problem that has arisen with the "Gee Whiz! Look at all the data we have!" approach to breeding is the identification of favorable sequences or haplotypes. There are certainly positive aspects to identifying favorable sequences, but there appear to be some negative aspects as well. Rare alleles (i.e., unstudied, new alleles), often get labeled as bad data or unreadable data and such data get tossed out, although other more tedious and costly procedures can be used (Zuk, et al., 2014). Lines lacking favorable sequences often are eliminated without testing. Both lead to a further narrowing of the already-narrow germplasm base.

Now, what is likely to happen to public maize breeding? Even if public maize breeders were to jump on the molecular bandwagon, there is not enough grant funding to sustain even one public maize-breeding program over the 15-year period it takes to evaluate program effectiveness. Perhaps funding for organic maize breeding might help, but again grant funding – even for a ten-year grant – is inadequate and really inappropriate. Hatch funding or its equivalent would be essential. And choosing which programs are worthy of support is difficult. If the USDA decided to support one or two such programs on a continuing basis, would one even be welcomed at most land-grant universities (remember the overhead, or lack thereof). GEM has been tolerated at Iowa State and NC State, but has certainly not had the welcome that molecular approaches have had (just count the new buildings if you want a crude score). At most institutions, the value of a program is measured by the value of the overhead monies generated, not by whether it is important and/or productive.

I have lobbied the major companies to endow field-breeding technician positions for a few critical programs. This would cost slightly more than $50,000 per position per year or a bit more than $1,000,000 for a fully funded endowment. Having seen what happened to the Agronomy Department at Iowa State after Raymond Baker (Pioneer's first breeder and the father of the commercial Iodents) left about $90,000,000 to the department, I'd be sure to include some clause transferring any substantial funds to the institution's biggest rival if the funds were not used as intended. Now, a fully funded field technician is not enough to guarantee a fully functional field program, but it would discourage administrators from closing a good program down automatically at the occasion of the retirement or departure of the breeder. This suggestion raised a few eyebrows at the American Seed Trade Association Corn and Sorghum meetings, but seemed to meet with at least some interest from the Clif Family Foundation, a group with strong organic interests.

The Big Three (Monsanto, Pioneer, Syngenta) all basically share the same germplasm base, although Pioneer seems to still have a few sources that have yet to be purloined. The three combined, along with their affiliates, control about 85% of the U.S. market. I regard this as dangerous. There are existing diseases in Africa, Asia, and South America for which there is little, if any, resistance among U.S. lines. And unlike the brief Southern Leaf Blight problem of the early 70s (associated with the T form of cytoplasmic male sterility), there are no seed packets on the shelf that would quickly solve a new problem.

At North Carolina State University, we have been able to show that competitive, temperate-adapted, all-tropical lines (Table 2) can be developed, but the time frame for this is about 15 years, and none of the genomic magic touted by enthusiastic molecular geneticists is apt to shorten that time frame. Defensive breeding does not need to be started now – it needed to be started in the 1990s or earlier. And defensive breeding, does not mean programs for resistance to Northern or Southern Leaf Blight, Anthracnose Stalk Rot, Fusarium Ear Rot or Goss's Wilt.

These are well known diseases with lots of readily available resistance among adapted materials. We need diverse programs using a broad array of germplasm, preferably using germplasm that is elite somewhere outside the boundaries of the U.S. The GEM program fulfills that role to some extent, but much of GEM is devoted to only 25%-tropical, 75%-temperate- or 50%-temperate, 50%-temperate-exotics that have been sampled and re-sampled for over 50 years.

Major companies should have routine procedures for introducing their elite foreign lines – some of which do carry resistance to potentially dangerous foreign diseases - into their domestic breeding programs. We have done a far better job of exporting U.S. germplasm for breeding overseas than we have of importing promising materials from overseas for breeding in the U.S.

Needed Traits and Programs

Perhaps most needed are nitrogen use efficiency, stress tolerance, and stalk- and ear-rot resistance. Over time, nitrogen costs are only going to increase. Global warming may help Canadian farmers, but alternating floods and droughts play havoc within much of the U.S. Stalk rots are accentuated by stress. And the ear rots are a human and animal health issue. While transgenics may help with some of these issues, relatively little of the native variation in maize has even been explored. Much of it can't be evaluated because it hasn't been adapted to the U.S. Sorghum, a relatively minor crop in the U.S. compared to maize, has had an excellent photoperiod conversion project since the 60s. Why is there not one for maize? This is a serious question that has been ignored for 50 years. It is perhaps the most serious maize breeding/maize germplasm failure of the USDA-ARS, which otherwise has had a pretty sterling record.

Breeding Approaches

Small-scale, backyard breeding will not keep pace with the progress being made by even the slowest of the major companies. The current ex-PVPs are also not very exciting (Tables 3 and 4). It is not even clear that the more recently released ex-PVPs are much better than the earlier ones. Regardless of tester, the best of the ex-PVPs only rarely out-yielded LH132 x LH51, LH200 x LH262, HC33 x TR7322 or Garst 8288, all rather old hybrids. The only DeKalb or Pioneer hybrid that yielded less than any ex-PVP was P33V15, an obsolete hybrid that was out-yielded by two crosses of PHN47 (again, regardless of tester). The DeKalb and Pioneer checks are far from new, and none of the checks are 'traited'. In one second-year yield trial ending in 2012 and in a third year trial ending in 2013, B73 out-yielded every ex-PVP. In a second year trial ending in 2011 and a third-year trial ending in 2012, Mo17 out-yielded every ex-PVP.

What are the threatening diseases for maize? Some are listed in Table 5. Hopefully, there are major genes for resistance and closely linked markers that will speed their deployment, but there are no guarantees, so resistance breeding is needed now (or sooner!).

The cost of a maize-breeding program is fairly high (Table 6), but is not nearly the cost of failing to carry out the maintenance of our germplasm accessions (Table 7). These are currently in a scandalous state, and for several years winter nursery regenerations have not been possible. There is a 12-year backlog, mostly of accessions that can only be increased under short-day, winter nursery conditions.

While sorghum has had a useful photoperiod conversion project for years, there has been no attempt to have one for maize, a much more important crop. Approximate costs for a modest program of photoperiod conversion for maize are presented in Tables 8 and 9.

If the companies had independent breeding programs, organic breeders could conceptually license single crosses from different companies and cross them to produce competitive double-cross hybrids. But (1.) even hybrids from different companies are too inter-related for that, and (2.) based on past response, Pioneer is unlikely to allow that with its hybrids.

The major companies are concentrating on "traited" hybrids, but most are generally backcrossing traits into lines rather than using 'forward breeding' (crossing lines together that share the same "trait"). While traited insect resistance may be little more than a break-even situation for some farmers, herbicide resistance is at the top of almost all conventional farmers' wish lists. Weed-free fields are a goal that has been achievable until recently with Round Up resistance (RR). Today, Round Up has been over-used, and weed resistance has developed, especially with some pigweeds and horseweeds. At least in the South, the trait has lost much of its value, and resistance is rapidly marching north. Liberty-Link seems to be taking the place of RR and inviting the same type of problems a few years down the road. It is notable that the few major genes that have been utilized in maize (*cms-T*, Ht_1, Rpp_9, several *bt*s, RR) have each lasted about 15 years before systematic breakdown or some form of resistance has arisen.

At some point, organic promoters are going to have to choose between purity and progress. That may not be soon, as directed mutagenesis (Koch, et al., 2013) and perhaps cis-genesis may substitute somewhat for transgenesis. Eventually however, there will be really valuable transgenes that will become universally used. It may be 50 years from now; it may be 100 or it could be 10. A transgene from, say, the University of Wisconsin, eliminating aflatoxin from maize, peanut, rice, and wheat would be hard to ignore, despite the dangers of uniformity involved. Most organic growers probably use d-con (also from the University of Wisconsin) around their houses and barns. Would 'afla-con' in their maize fields be all that different? (No, we don't eat d-con, but a large number of folks do take warfarin, its active ingredient, as an anti-coagulant).

The purpose of transgenic traits has recently been questioned by Latham (2014). Rather than assistance to farmers (such as Pioneer's famous "Long Look" dating to at least 1952), Latham suggests that transgenes have really been used to gain monopoly control of the seed supply industry. He suggests that many shining examples of transgenetic progress that are often cited (golden rice, disease-resistant cassava, etc.) are much less successful when looked at more carefully, and he berates the press for not digging into the issues.

Table 2. Strong Public Maize Breeding Programs

Strong Maize Breeding Programs in the 1900s	
1. Connecticut	14. Indiana
2.New York	15. Wisconsin
3.Delaware	16. Illinois
4.Pennsylvania	17. Minnesota
5.Virginia	18. Iowa
6.North Carolina	19. Missouri
7.South Carolina	20. Arkansas
8.Georgia	21. North Dakota
9.Florida	22. South Dakota
10.Ohio	23. Nebraska
11.Kentucky	24. Kansas
12.Tennessee	25. Texas
13.Michigan	
Strong Maize Breeding Program Today	
1. North Carolina	4. Iowa (GEM)
2. Tennessee	5. North Dakota
3. Wisconsin	6. Texas

Table 3: 5 Pioneer Sister-Line Testers

(2 yr., 8 env.) HYBRIDS	YIELD T/HA	% MOIS	% EP
2 PH NSS x NC296	9.06	19.9	97
3PH SS x NC296	9.40	20.0	98
DeKalb 697	8.76	19.6	93
Pioneer 31D58	8.81	19.2	99
Pioneer 31G66	9.10	19.1	99
Pioneer 31P41	8.92	19.0	100
Pairwise .05 LSD	0.69	0.7	5
C.V.%	8	4	5

Table 4. Best ex-PVPs Tested for 3+ Years*

PEDIGREE	YIELD T/HA	% MOIS	% EP
4 YEARS 19 ENV 2009			
DJ7 x FR615.FR697	8.01	16.9	97
LH51 x FR992.FR1064	7.90	16.6	98
LH132 x FR615.FR697	7.76	16.8	98
PHG39 x FR615.FR697	7.89	16.8	98
Seag.17xFR992.1064	8.28	16.1	97
DeKalb 697	9.87	18.8	93
Garst 8288	8.79	19.2	94
Pioneer 31G98	9.97	17.3	98
Pioneer 32D99	10.13	19.7	94
LSD .05	0.44	0.4	3
C. V. %	9	4	5
3 YEARS 14 ENV 2010			
LH59 x FR992.FR1064	6.57	15.7	98
NK794 x FR615.FR697	6.48	15.5	99
DeKalb 697	8.33	18.3	95
Pioneer 31D58	8.28	18.4	99
Pioneer 31G98	8.60	17.4	96
LSD .05	0.74	0.6	2
C. V. %	13	5	3
3 YEARS 14 ENV 2010			
LH51 x NC368	8.02	18.3	99
NK740 x NC368	7.76	17.4	98
PHG35 x NC368	7.91	17.6	98
PHG84 x NC368	7.79	18.7	98
DeKalb 697	8.73	18.8	97
LH200 x LH262	7.56	18.5	97
Pioneer 31D58	8.40	18.8	99
LSD .05	0.60	0.5	2
C. V. %	11	4	3
3 YEARS 14 ENV 2010			
DKHBA1xLH244.LH245	7.33	17.5	99
LH60 x LH244.LH245	7.33	18.2	97
Seag.17 x LH244.245	7.59	16.6	98

LH132 x LH51	7.22	17.6	99
LH200 x LH262	7.88	18.2	98
LSD .05	0.51	0.5	2
C. V. %	10	4	3

PEDIGREE	YIELD T/HA	% MOIS	% EP
3 YEARS 14 ENV	**2010**		
NKW8304 x LH287.283	7.46	18.1	90
NS701 x LH287.LH283	7.73	16.8	89
PHT55 x LH287.LH283	7.69	18.4	86
B73 x LH287.LH283	7.19	16.9	88
DeKalb 697	8.40	19.5	91
Garst 8288	8.01	19.3	93
Pioneer 31D58	8.33	18.9	94
LSD .05	0.60	0.5	5
C. V. %	11	4	7
3 YEARS 14 ENV	**2010**		
PHN47 x FR615.FR697	7.64	18.3	97
PHN47xFR992.FR1064	7.65	18.6	97
DeKalb 697	8.43	18.5	95
LSD .05	0.52	0.5	4
C. V. %	10	4	6
3 YEARS 15 ENV	**2012**		
NKW8555xFR615.FR697	6.91	16.4	90
PHM57 x FR615.FR697	6.86	17.6	90
B73 x FR615.FR697	6.42	16.2	90
Mo17 x FR992.FR1064	7.10	15.8	89
DeKalb 697	8.21	18.9	90
Pioneer 31G66	8.40	18.2	88
Pioneer 33M54	7.79	17.7	92
LSD .05	0.55	0.6	4
C. V. %	11	5	7
3 YEARS 14 ENV	**2012**		
Carg2369xLH287.283	7.59	17.7	86
DKHBA1xLH287.LH283	7.20	18.4	90
DKPB80xLH287.LH283	7.25	17.3	90
LH132 x LH287.LH283	7.20	18.2	92
NK792 x LH287.LH283	7.23	16.9	90
NKW8304xLH287.LH283	7.46	18.1	90
NS701 x LH287.LH283	7.73	16.8	89
PHG39 x LH287.LH283	7.21	17.9	92
PHT55 x LH287.LH283	7.69	18.4	86
PHW52 x LH287.LH283	7.17	18.4	91
B73 x LH287.LH283	7.19	16.9	88
DeKalb 697	8.40	19.5	91
Garst 8288	8.01	19.3	93
Pioneer 31D58	8.33	18.9	94
LSD .05	0.60	0.5	5
C. V. %	11	4	7
3 YEARS, 14 ENV	**2013**		
DK6M502xFR1064.132	8.44	18.2	95
LH193 x LH287.LH283	8.32	17.6	96
NKW8555xLH287.LH283	8.81	17.3	92
PHM57 x LH287.LH283	8.76	18.6	90
B73 x LH287.LH283	8.99	17.4	91
DeKalb 697	9.80	19.0	93
Pioneer 31D58	10.00	18.8	97
Pioneer 33M54	9.58	18.4	96
LSD .05	0.50	0.5	4
C. V. %	9	4	6

Table 5. Best ex-PVPs Tested For Two Years*

PEDIGREE	YIELD T/HA	% MOIS	% EP
2 YEARS 10 ENV	**2007**		
DJ7 x FR615.FR697	7.80	16.0	95
LH51 x FR992.FR1064	7.81	15.6	98
PHG39 x FR615.FR697	7.87	15.6	98
Seag.17xFR992.1064	8.42	15.1	95
DeKalb 697	10.06	17.8	94
Pioneer 31G98	10.10	16.0	97
Pioneer 32D99	10.18	18.3	94
LSD .05	0.57	0.6	4
C. V. %	9	4	5
2 YEARS 9 ENV	**2009**		
LH59 x FR992.FR1064	7.20	16.8	99
NK794 x FR615.FR697	7.38	16.7	99
DeKalb 697	9.04	19.7	94

Pioneer 31D58	9.24	19.7	99
Pioneer 31G98	9.40	18.8	97
Pioneer 32D99	9.74	20.5	94
LSD .05	0.70	0.8	6
C. V. %	11	5	6

2 YEARS 9 ENV		**2009**	
DKHBA1xLH244.LH245	8.12	19.0	99
LH59 x LH244.LH245	7.85	18.4	96
LH60 x LH244.LH245	7.93	19.5	96
LH123HtxLH244.LH245	7.88	18.5	98
NK740 x LH244.LH245	8.09	18.2	96
Seag.17 x LH244.245	8.14	18.0	98
Garst 8288	8.12	20.7	98
LH200 x LH262	9.03	19.7	98
Pioneer 31G66	10.00	20.4	98
Pioneer 31P41	9.85	19.8	99
Pioneer 33M54	8.39	20.1	100
LSD .05	0.63	0.7	3
C. V. %	9	4	3

2 YEARS 9 ENV		**2009**	
DKHBA1 x NC368	8.59	20.0	97
LH59 x NC368	8.52	19.0	98
PHG35 x NC368	8.66	19.3	99
DeKalb 697	9.66	20.5	98
Garst 8288	8.59	21.1	99
Pioneer 31D58	9.43	20.3	99
Pioneer 31G66	9.87	20.1	99
LSD .05	0.66	0.7	3
C. V. %	9	4	3

2 YEARS 9 ENV		**2009**	
PHN47 x FR615.FR697	8.45	19.6	98
PHN47xFR992.FR1064	8.39	20.1	96
DeKalb 697	9.19	20.0	94
Garst 8288	8.11	20.2	97
Pioneer 31G66	9.02	20.0	98
Pioneer 31P41	8.69	19.7	99
Pioneer 33M54	8.50	19.5	99
Pioneer 33V15	8.24	19.0	97
LSD .05	0.71	0.8	5
C. V. %	11	5	5

2 YEARS 10 ENV		**2011**	
LH51 x NC368	7.63	17.0	90
NK740 x NC368	7.53	16.4	88
B73 x FR615.FR697	6.52	16.0	87
B73 x LH287.LH283	6.83	16.1	84
Mo17 x FR1064.LH132	7.15	15.2	87
Mo17 x LH244.LH245	7.29	15.2	88
Mo17 x NC368	7.32	16.1	87
NC296 x NC368	7.98	16.9	83
DeKalb 697	8.11	17.5	87
LH132 x LH51	6.80	16.9	89
LH200 x LH262	6.95	17.4	87
Pioneer 31D58	8.38	17.8	93
Pioneer 31G98	8.59	16.5	88
LSD .05	0.69	0.6	5
C. V. %	11	4	6

2 YEARS 10 ENV		**2011**	
NKE8501xFR992.1064	6.70	16.1	88
NKW8555xFR615.FR697	6.80	15.4	86
PHJ70 x FR615.FR697	6.60	15.7	88
PHM57 x FR615.FR697	6.83	16.4	87
PHN29 x FR615.FR697	6.42	13.7	91
B73 x FR615.FR697	6.29	15.1	87
Mo17 x FR992.FR1064	7.05	14.8	87
DeKalb 697	8.23	17.6	89
Garst 8288	7.35	17.5	88
Pioneer 31G66	8.20	17.1	86
Pioneer 33M54	7.68	16.8	92
LSD .05	0.78	0.8	7
C. V. %	15	6	9

2 YEARS 9 ENV		**2011**	
Carg2369xLH287.283	7.65	16.9	86
NKW8304 x LH287.283	7.65	17.3	86
NS701 x LH287.LH283	7.88	16.1	84
PHG39 x LH287.LH283	7.45	17.2	89
PHT55 x LH287.LH283	7.88	17.6	82
B73 x LH287.LH283	7.52	16.2	85
DeKalb 697	8.52	18.4	89
Garst 8288	7.86	18.9	91
LH200 x LH262	7.40	18.4	85
Pioneer 31D58	8.23	18.3	92

LSD .05	0.72	0.8	6
C. V. %	12	5	7
2 YEARS 9 ENV	**2012**		
LH193 x LH287.LH283	8.61	18.2	93
NKW8555CxLH287.283	8.76	17.8	88
B73 x LH287.LH283	8.90	17.8	87
DeKalb 697	9.44	19.7	90
Garst 8288	9.30	19.8	92
Pioneer 31D58	9.88	19.4	95
Pioneer 33M54	9.60	18.9	94
LSD .05	0.68	0.8	6
C. V. %	10	5	8

	YIELD	%	%
PEDIGREE	T/HA	MOIS	EP
2 YEARS 10 ENV	**2012**		
WIL900xFR1064.LH132	8.28	18.7	88
Mo17 x FR1064.LH132	8.08	17.2	86
DeKalb 697	8.66	19.7	81
Garst 8288	8.54	20.0	87
HC33 x TR7322	7.71	17.0	87
LH200 x LH262	7.96	19.6	84
Pioneer 31D58	9.35	19.1	87
Pioneer 31G66	9.82	19.4	86
Pioneer 31P41	9.93	19.2	88
Pioneer 31R88	8.57	20.2	87
LSD .05	0.67	0.7	5
C. V. %	10	4	6

2 YEARS 10 ENV	**2013**		
DK6M502AxFR1064.132	8.40	18.3	99
DKF118xLH287.LH283	8.63	17.8	99
DKMM402AxFR1064.132	8.35	16.6	99
DeKalb 697	9.72	19.1	99
LH200 x LH262	8.15	18.8	100
Pioneer 31G66	9.59	18.7	99
Pioneer 31P41	9.91	18.2	99
LSD .05	0.66	0.6	3
C. V. %	10	4	3

*Notes to Tables 3 and 4:
FR992.FR1064, FR1064.LH132 (sometimes written as FR1064.132), LH244.LH245, and NC368 are all Stiff Stalk (female) testers.

FR615.FR697 and LH287.LH283 are non-Stiff Stalk (male) testers.

Year listed at the top of each sub-section is the final year for each trial.

Table 6. The Threatening Diseases?

Examples
Downy mildew (Asia) Streak Virus (Africa) Lethal Necrosis (Africa) Mal de Rio Quarto (South America) Maize Red Streak (Europe) Late Wilt (Europe)
====================
Hopefully, there will be major resistance genes for these and good markers as well.

Table 7. What is the Cost of a Public Breeding Program

About $500,000 for start up.
About $150,000 project expenses/yr.
$100,000 breeder salary
$50,000 technician salary
====================
$300,000 minimum annual costs (see Belanger, 2013).

Table 8. The Financial Situation of Maize gerplasm at NCRPIS at Ames

	2013	2014
Salaries/Labor	$185k	$270K
Winter Nursery:	$0	$35k

Summer Nursery:	$20k	$
Supplies:	$30k	$35k
Total	$235k	$370k

Needed:$1 million/yr to clear backlog of old, mostly tropicals in 12 years.

Table 9. Cost of a Maize Photoperiod Conversion Project:

An Example:	
150 PIs/yr (P.Rico) F1s & F2s	$6k
150 PIs/year (Iowa) F2S1s	$30k
150 BC2s & BC2S1s (PR)	$6k
150 BC2S2s (IA)	$30k

Table 10. Personnel Needed

1 Project Leader in PR	$120k/yr
1 Tech in PR	$50k/yr
1 Project Leader in IA	$120k/yr
1 Tech in IA	$50k/yr
Temp Labor	$60k/yr
Supply/Repair Costs	$100k/yr
Sub-Total	$480k/yr
Grand Total	$660k/yr

This is ~half the annual GEM budget

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Keynote Paper # 3: "COULD GENEBANKS BE A POT OF GOLD AT THE END OF THE RAINBOW"?

Author: David Ellis

DAVID ELLIS is committed to the preservation of plant genetic
resources with decades of experience in academia, private industry and the public sector. He leads the genebank at the International Potato Center (CIP) in Lima, Peru, maintaining the global in-trust collections of potato, sweet potato and Andean root and tuber crop. CIP is among 15 centers of the Consultative Group on International Agricultural Research (CGIAR), dedicated to reducing rural poverty, increasing food security, improving human health and nutrition, and ensuring sustainable management of natural resources.

Could Genebanks be a Pot of Gold at the End of the Rainbow?

David Ellis[14]

Importance of Genebanks

Plant diversity is the source of genetic material for sustaining and enhancing agricultural productivity. The ballooning human population growth is likely the biggest challenge to food security in this millennium and beyond. Direct consequences of the unsustainable human population growth are that environmental habitats are being destroyed, global warming is continuing unchecked and critical plant diversity, essential for the development of new varieties, is being lost at rapid and unpredicted rates (Li and Pritchard 2009) that available conservation resources cannot keep up (Myers et al. 2000). Ironically, the development of improved varieties, which are the foundation of sustaining global food security and whose development *depends* on plant diversity, *displaces* such diversity. The loss of plant diversity coupled with the effects of political and social unrest, climatic disasters, and climate change increase the challenges faced to the needed doubling of food production in the next 20 years with less land and water than currently used. And this food must be more nutritious!

The gradual warming of our planet intensifies the immediate demand on plant breeders for sustaining and increasing food productivity. Targets for breeders include the biotic threats such as disease and insect resistance and of growing importance abiotic threats such as drought, heat, flood, and cold tolerance. One example in the Andes is that due to warming climates, insect and disease pressures are greater in areas traditionally used to cultivate native landraces of potatoes. Over the past few decades this has forced potato cultivation up 100 meters or more in elevation. For smallholder farmers, the primary producers across the developing world this can be ruinous as higher lands may not be readily available or centuries-old varieties and farming practices may not be suitable to new growing grounds.

Where can genebanks contribute to this seemingly insurmountable challenge? Genebanks hold vast collections of germplasm, any one of which could be the "silver bullet" or the one holding a traits(s) needed by the breeder to overcome one of the myriad of challenges farmers are increasingly facing, such as insect resistance, drought tolerance, or enhanced frost/heat tolerance. But no one accession will hold all the silver bullets and finding the one accession that does hold the one silver bullet can be akin to finding a needle in a haystack. Therefore, information systems, core collections allowing a sampling of the diversity in a subset of accessions, and expertise in the collection are paramount to finding that one accession with the needed allele(s) conferring a desirable trait. Success

[14] International Potato Center, Lima, Peru. (d.ellis@cgiar.org)

stories of germplasm collections highlight the need for maintaining these huge collections. The Hessian fly has accounted for losses of more than US $300 million in wheat production annually in Morocco alone, yet resistant varieties can reduce the damage to less than 1%. The screening of thousands of accessions of wheat and wheat relatives was needed to find 15 sources of resistance.

Natural and man-made disasters often leave farmland destroyed, farmers displaced and varieties which have evolved and been selected to be locally adapted over centuries vanished. The National genebanks holding these irreplaceable heirlooms of diversity were looted during the wars in Rwanda and Afghanistan, leaving the farmers who remained in these torn regions with no locally adapted seed (hdl.handle.net/10947/1311) to start the rebuilding process. Fortunately the idea of not putting all your eggs in a single basket is the standard for genebanking and hence, the genebanks from both Rwanda and Afghanistan had placed a duplicate of their seed collections in genebanks in other countries which repatriated these locally adapted accessions back to the war-torn countries to re-establishment and rebuild the agricultural systems in these countries.[5] A tsunami swamped agricultural land with saltwater in 2004, making many areas in Asia unsuitable for rice production. By screening over 100,000 rice accessions at the International Rice Research Institute (IRRI) in the Philippines, new varieties suitable for cultivation in these areas were found. (http://www.cgiar.org/consortium-news/cgiar-consortium-partners-with-global-crop-diversity-trust-to-revitalize-genebanks/). Genebanks also partner with indigenous communities by repatriating disease-free varieties collected in the past from the region that are no longer locally grown. An example of such work is the partnership between the International Potato Center (CIP) and Parque de la Papa in Peru. A strength of this collaboration is that the exchange goes both ways thereby building the diversity available in global collections.

In the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (SoWPGR-2) (2010) the Food and Agriculture Organization of the United Nations (FAO) estimated there were approximately 7.4 million accessions worldwide being maintained in approximately 1,750 ex-situ genebanks. Unfortunately only an estimated ~25% of these accessions are unique or genetically distinct and this estimation is likely optimistically high as very few accessions have been characterized at the molecular level. Despite this, many of the genebanks in developing countries lack the capacity for routine operations such as cleaning accessions of diseases, training of staff, employing best genebank practices or realizing sustainable national support systems (infrastructure, funding, legislation, databases). Many of these 1,750 genebanks could consist of nothing more than an air conditioned seed storage room with unreliable electricity, minor sanitation facilities and much good will. Such minimal genebanks are the most vulnerable as their collections are likely not backed up nor of good initial quality.

Complementary to the ex situ genebanks for the conservation of genetic diversity in landraces and crop wild relatives are the establishment of on farm or in-situ sites for the conservation and monitoring of varieties or species in a natural setting. A challenge in the establishment of in situ sites is how to sustain and thus maintain these sites. Long-term, sustainable economic benefits to the farmers or custodians of the sites are of paramount importance in the long-term sustainability of in-situ sites. Studies are needed in areas critical for sustainable management of the sites including income generation, enhanced nutrition and long-term sustainability of the farmer's livelihoods. Coupled with this is the need for long-term documentation of the temporal and spatial dynamics of in-situ conserved diversity and how traditional knowledge can play a role into the long-term conservation strategies.

Global Exchange of Genetic Resources

In June of 1992 a pivotal point in the conservation, sustainable use, and fair and equitable sharing of benefits from the use of genetic resources was reached with the launching of The Convention of Biological Diversity (CBD) at the United Nations Conference for Environment and Development (the Rio Earth Summit) (www.cbd.int). Since this time, the CBD has defined the regulation, management, and limitation to the use of genetic resources by individual countries Kusar 2011). Although much needed and written and implemented with huge wisdom, the CBD, like many international treaties was broad and all-encompassing with language and articles based on compromise as much as need. Of primary importance is that the CBD firmly established a nation's sovereignty over their genetic resources and that these genetic resources had an economic value that should be shared by the country (and farmer) of origin. In principal the native communities responsible for the centuries to millennia of selection to fix alleles and develop landrace cultivars should be compensated for this work and there should be an economic or other benefit returned from the use of these genetic resources to these communities. No one can argue that this is fair yet how best to define the economic value of individual collections in a plant genebank and what sort of benefit sharing system was equitable was undefined. This left the conservation, collection and exchange of genetic resources in a state of limbo as without a definition of economic value the countries were left not wanting to risk sharing something that might later have value. Collections and exchange of genetic resources slowed as nations worked through this very complicated new global awareness. Over time, the granting of collection permits decreased even to scientists within party nations.

In a response to this uncertainty and in an effort to increase and better define the terms under which access and benefit sharing associated with plant genetic resources would occur, the plant genetic resources community in consultation with party nations of the CBD initiated the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA), a treaty defining the conservation, access, benefit sharing, farmers rights, and sustainable use of Plant Genetic Resources for Food and Agriculture (PGRFA) (International Institute for Sustainable Development 2012; (www.planttreaty.org). Coming into force in June 2004 after seven years of negotiation, the ITPGRFA created the multilateral system for the facilitated access to 35 crop genera and 29 forage species, collectively denoted as Annex 1 crops. Material covered under the ITPGRFA is distributed under the terms of the Standard Material Transfer Agreement (SMTA). Access and benefit sharing requirements are defined and are clearly aligned with the CBD. It should be noted that again due to the level of compromise needed to negotiate these international treaties, some very important crops such as soybean, sugarcane, peanuts and wild *Manihot* species (relatives of cassava) are not Annex 1 crops and therefore may not come under the SMTA or ITPGRFA.

Access and Benefit Sharing (ABS) is firmly established and widely accepted as the principal in the distribution and use of plant genetic resources. Yet despite this acceptance, the implementation of ABS continues to limit distribution and use. The reality is that the regulatory climate around the distribution and use of plant genetic resources is a continually changing, dynamic, complicated and often along a rocky road. ABS is one element in the altering regulatory environment but is often a driving force in this rocky road. Although well defined in the ITPGRFA, benefit sharing is still slow to be seen by the developing world and is poorly understood at the regulatory level. This misunderstanding often results in the restricted access through complicated and changing regulatory pathways or the difficulty in obtaining permission to collect crop wild relatives to fill gaps in ex situ collections.

Despite these hurdles, progress is being made in the understanding of the need to conserve and that the *use* of plant genetic resource is of benefit to all. No country is self-sufficient in native genetic resources to feed their nation. For example, maize originally from Mexico is grown in virtually all nations of the world, as is wheat originally from the Middle East, potatoes originally from Peru (Spooner et al. 2005), rice from the Indochina region (Fuller 2011), and soybeans from China. The evolution, selection, and breeding of domesticated and improved varieties is of importance to all farmers, in particular farmers from poorer or developing nations who may not have access to the benefits of modern agriculture. However, with or without the resources of modern agriculture the reliance on the best germplasm for your particular region, crop and farming system is primary to long-term survival and sustainability. The green revolution would not have been possible if not for the wheat variety Norin 10, derived when a Japanese wheat crossed with the U.S. variety Furtz in 1917 and then subsequently crossed with a Turkish variety in 1925. Following 7 cycles of successive selection Norin 10 was introduced in 1935. A U.S. agricultural advisor thought that this germplasm could be of use so he arranged to have samples shipped back to the U.S. Little did he know that Norin 10 would impact over ¼ of the world's population (Wilkes and Williams 1983)!

Norin 10 could serve as an example of a variety where the use of multiple genetic resources in the generation of a variety is complex involving many different sources of germplasm from many different countries resulting in potentially conflicting regulatory system(s) governing the access and use of the plant material. It is not difficult to imagine the hurdles encountered in maneuvering the regulatory pathway if each country has its own set of regulations. Clearly a single global regulatory system for ABS of all plant genetic resources is needed as envisioned in the ITPGRFA. While the pedigree of Norin 10 is relatively straightforward with germplasm from as few as 3 different countries, the use of other modern cultivars could be far more complex without a single ABS system. Examples include:

-The wheat variety 'VEERY' which is the result of 3,170 different crosses involving 51 accessions from 26 countries;

-After screening over 6,000 accessions of *Oryza nivara,* a species of wild rice, resistance was found in a single accession which is responsible for resistance to grassy stunt virus disease in tropical rice varieties for the past 36 years (McCouch 2013);

-To develop high-yielding, salt-tolerant rice varieties, IRRI scientists made 34,000 crosses over 20 years with *O. coarcata* before getting a single viable seedling It will now take 4-5 years of breeding to develop a new variety.

-The potato variety 'Cooperation 88' (C88), a Late Blight (LB)-resistant variety developed jointly by CIP and the Yunnan Normal University, was derived from the female parent I-1085 (Sita) from the Indian potato breeding program which contained several potential sources of LB resistance from the wild potato species S. demissum and whose parentage can be traced back to the German potato breeding program of the early 1900s with a pedigree consisting of a minimum of 17 varieties and breeding lines. I-1085 was then crossed with bulk pollen from 15 clones, each of which contained extensive and diverse pedigrees from numerous origins. The benefit of C88 is estimated to be US $192 million per year to poor farmers of the world with a potential overall economic benefit of $465 million per year when fully adopted (Robinson and Srinivasan 2013). As expressed by Robinson and Srinivasan "without CIP germplasm and CIP breeding expertise [the development of C88] would not have been possible" (ibid.).

Genebanks are not museums

Clearly the development of a particular improved variety of a crop depends highly on countless sources of germplasm and it is the responsibility of the genebank for the long-term storage of this germplasm until it is needed. Since one cannot predict which one accession out of the of thousands of accessions stored for any one crop in a genebank will contain the allele(s) needed to counter the challenge at hand, genebanks are charged with keeping each and every accession alive and in a usable form. At CIP, our goal in the genebank is to keep germplasm representing the diversity of the crops we work with alive, in a readily usable form for at least 100 years.

Seed is the most common form of conservation and we are fortunate that in the evolution of seeds, Mother Nature developed a very resilient package to keep the embryo alive for decades under certain conditions. Approximately 80% of plants produce *orthodox* seed, seed which is desiccation tolerant and can be stored frozen (-20°C) and survive for decades to centuries. An even higher percentage of crop plants have orthodox seed as the domestication of a crop relied on a primitive farmer to be able to select and store seed with improved traits over the winter and have this seed viable the following years. The majority of the accessions in the global genebanks are stored dried and frozen. In contrast to recalcitrant seed, there are a relatively few crop plants (many tropical fruits, cocao, coffee, oaks) whose seed do not tolerate desiccation, termed *recalcitrant* seed, and therefore cannot survive freezing. Numerous active research programs are focused on the development of methods for the long-term conservation of species with recalcitrant seed yet such programs are by necessity focused on crop-by-crop approaches.

In addition to crops propagated and stored as seed, there are many crops maintained and propagated vegetatively as clones. These include mint, most fruit crops, potatoes, sweet potatoes, bananas, many tree crops, hops, sugarcane and strawberries. Germplasm collections of tree and other woody perennial crops are mostly maintained as field collections which are highly vulnerable to loss from biotic and abiotic factors. The preferred storage method for most clonal crop collections is in tissue culture as an in vitro collection. Most germplasm collections of the major clonal crops are stored as such. Although more costly than field collections to maintain, storage of in vitro collections have advantages such as facilitated back-up at distant locations decreasing the risk of loss due to a catastrophe at the primary storage site and facilitated international use due to the ability to maintain and ship clean phytosanitary certified plants.

Cryopreservation, storage in liquid nitrogen (LN) at -196°C offers unique opportunities for long-term storage of both recalcitrant seed and clonal crops with a potential storage life of centuries. Whole seeds or embryonic segments from recalcitrant seed, dormant buds from woody perennials, somatic embryos or shoot tips from in vitro cultures are all potential sources of tissues for cryopreservation of germplasm collections. Methods for cryo are species specific and all involve a desiccation or cryoprotectant treatment followed by either slow cooling or direct plunging to -196°C.

Regardless how good the maintenance of our genetic resources collections is, the collections are of limited value unless they are used. Key to use is the association of as much information as possible with each and every accession. Further, information needs to be in a vibrant form, user-friendly, multi-disciplinary, in an accession-specific database housing all known passport, characteristic, phenomic and genomic information. The analogy of a genebank to a library full of books is good and commonly used. Each book has huge potential value yet if the only information available to users is the name and date of publication on a card catalogue, this makes targeting a particular book to obtain the information you need very difficult. As more information is available on the card catalogue, it aids in reducing the number of books one needs to search through to find the one book with the information needed. If the card catalogue is a publically accessible, web-based searchable database which permits simultaneous multi-factor searches, it further facilitates use which can potentially expand beyond its initial intent. The more information that is available on each book in such a database, the greater the potential is for users to look at only a few books to find what they need rather than thousands of books. For plant breeding, screening a thousand accessions may be a show-stopper where screening a few dozen targeted accessions is doable.

With limited genomic and phenomic information currently available on an accession basis, it is often deemed too 'risky' for breeders to wade into the unknown waters of crop wild relatives (CWR) where a potential treasure chest of agronomic traits exists. What breeder today can afford the 20 years it took to make a single successful cross of O. coarcata with O. sativa to obtain enhanced salt tolerance in high-yielding rice varieties? And this effort was only possible due to known salt tolerance in O. coarcata. For the countless other genebank CWR accessions with little information available, the risk is just too high due to the time involved in searching out the form of new resistance(s) or desirable traits. What is surprising however is that the percent of the genebank accessions used is relatively high rate. In the case of rice at IRRI, 70% of the individual genebank accessions in the collection have been requested over the past 10 years (R, Sackville-Hamilton, personal communication). The data indicates there is no lack of use of genebank accessions, however, data on why this material was requested and how it is used is currently poor. As is data on how many accessions ultimately contribute to new varieties. One can only guess that the percent used for breeding of new varieties is far lower than the percent distributed.

The operating costs of genebanks are minuscule when viewed in the context of the value of the global agricultural sector. However, cutbacks in FY12 USDA-ARS funding resulted in the closure of one of the genebanks in the National Plant Germplasm System (NPGS).

This following a five year period (2007-2011) when visits to the GRIN website increased exponentially inferring increasing interest confirmed by a steady increase in germplasm orders. During this same period, the budget for the NPGS increased only by approximately 2%/year (from ~$42 million to ~$47 million), for a net loss per year after on cost of living and mandatory personnel adjustments. Interestingly this is roughly comparable to the cost on a genebank-by-genebank basis adjusted for 2016 $USD of the maintenance of the global eleven CGIAR genebanks (2012-2016) at ~$21.5 million per year (http://library.cgiar.org/bitstream/handle/10947/2567/Support_Center_Genebanks_proposal_2012.pdf). One must caution however that the comparison on costs is only relative as comparing two genebanks is like comparing apples and oranges.

Genebanks in a changing technological world

As genebank managers it is important researchers want to use the collection but what is of growing importance is that the collection is used in an efficient way to aid in the development of new varieties and strategies to feed the growing global population. Of critical importance is the development of new varieties to help advert poverty, malnutrition and hunger. Particularly exciting is the rapid advance in genomic capabilities where now sequencing entire collections are possible. Unfortunately the present sequencing efforts are very crop specific with individual efforts between crops often not coordinated at all. Databases may or may not be linked in a way to offer multidisciplinary and across crop use. There is a mixed bag of public accessibility to the data and seldom, are these efforts tied back to genebank accessions. Genomic analysis of CWR is often done on one to a few representative accessions for each species and efforts rarely start with the genebank asking which accession(s) are the most widely used or important for these genomic research efforts. In essence, genebanks have been invisible and not partners to most of these initiatives and hence valuable information is not tied to the genebank accessions for all to benefit from.

In fairness, genomic capabilities are progressing so rapidly that researchers are struggling to understand how best to use and apply the data being generated. The need for advanced bioinformatics capabilities and tools has been widely accepted and this has been rightfully given strong priorities. Moving forward, we will find numerous novel applications yet tying genomic information to genebank accessions to facilitate and speed breeding efforts must be on the priority lists. Further challenges include the fact that different communities and disciplines have different needs, vocabulary, concerns, objectives and endpoints for new developments, data analysis and generation as well as dissemination of information. Coupled with these discipline specific needs are crop-specific challenges, such as varying ploidy levels (cultivated potato includes accessions which are diploid, tetrapoid, pentaploid and hexipolid) and vast genomic diversity within a ploidy level, with the use and application of these technologies. To say for example that a new technology can be applied to the cultivated potato collection by testing only a handful of accessions from one ploidy level may be misleading and of limited value overall to breeders seeking to uncover hidden treasures in CWR or other diverse genebank accessions.

Now, more than ever, breeders need information on genebank collections and accessions. Using the library analogy, wouldn't it be helpful to be able to link books with topics, even if the topic were a sentence hidden in a thousand page book. Also what if parts of sentences, words and even letters in the books could be searchable in a multitude of ways to satisfy a broad range of users' requirements, needs and curiosities. Genebanks, genomic researchers, bioinformaticians and breeders need a paradigm shift in linking information back to genebank accessions to facilitate targeted use, uncover potentially valuable alleles and allelic combinations in new germplasm and if possible simplify and shorten the breeding cycle. Trait information generated in breeding programs needs to be tied to accessions and we need better genomic information on each accession to allow associations between accessions much like we might do in a library by linking paragraphs (QTLs), words (genes) and letters (SNPs), not to mention the emotional, social and cultural meanings that these words and letters might have (biochemical pathways). More directed genotype x environment research needs to be tied to genomic sequencing of individual accessions to mine these vast and diverse resources.

Changing tides

With whole, multi-genome sequencing becoming a reality, so does uncovering the genetic library of genebank holdings. Programs utilizing these advances have begun and are advancing rapidly, starting with crop-specific community support of large and vast research programs with goal of public dissemination of the data a priority to accelerate use and advance benefits to end-users from these programs. Examples of programs linked to genebank accessions and/or breeding lines include:

-Seeds of Discovery (SeeD)· an initiative of Mexico's Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) in partnership with several partners including genebanks at CIMMYT and the Centro Nacional de Recursos Geneticos (CNRG). SeeD was conceived to directly apply DNA-sequencing platforms to characterize the wheat and maize genetic diversity conserved at/in these Mexican genebanks. Some of their stated themes include information management, pre-breeding, identification of the genetic architecture of complex traits and filling genetic gaps in these genebank collections to ensure existing genetic diversity is conserved.

-The *3000 Rice Genome Project* a partnership between IRRI, the Chinese Academy of Agricultural Sciences (CAAS) and BGI-Shenzhen to re-sequence a large collection of accessions from the IRRI and CAAS genebanks. To date, 3,024 accessions been genome sequenced and these sequences have been aligned to the japonica Nipponbare genome to identify variants at tens of millions loci. Seed from the sequenced accessions is being made available to the research community to broaden the phenotyping for high priority breeding traits as well as for genetic, physiological and biochemical studies. One goal of this project is to provide enabling technology for the complete sequencing of the 110,000+ accessions in the IRRI genebank.

-The *150 Tomato Genome Re-Sequencing Project* (www.tomatogenome.net) is a private, public government partnership headed up by researchers at Wageningen UR and BGI to understand and explore the genetic variation in tomato. The project hopes to find important traits lost during domestication to aid in the sustainable production of food by decreasing the time for the development of new tomato lines.

-The *Germplasm Enhancement of Maize* (GEM) is a granddad compared with the sequencing projects above but is worth mentioning as in the past 20 years GEM has done an incredible job at introgressing exotic (maize landrace) accessions into commercially valuable inbred lines to facilitate the use of these exotic alleles in breeding programs. With a mission of increasing the diversity in U.S. maize germplasm through a collaborative government, industry and academic partnership, GEM should be held up as a model for prebreeding with over 260 released varieties. One of GEM's strengths is the strong private-public partnership which has resulted in placing exotic germplasm in a commercially viable inbred background which is in a form usable by breeders.

Building, partnering and advancing with projects such as the initiatives mentioned above are other broader initiatives to facilitate the use of genebank material through enhanced genomic and phenotypic screening of genebank accessions. Two are worth mentioning here for their view of enhancing the awareness of the larger plant science community:

1) Diversity Seek (DivSeek) (formally *SeedSeq)*, with the goal of harnessing the power of crop diversity to feed the future, is a new just developing initiative aimed at consolidating genomic projects globally with phenotyping projects and genebank accessions. The hope is to facilitate the sequencing of the global genebank collections and tie these sequences to phenotypic traits in a database designed to fit the needs of searches from the different multi-disciplinary research communities in such a way so each can customize their searches to obtain targeted accession-specific information in a format usable to each community. The vision is a database that will allow breeders to pinpoint the alleles they are interested in and then go directly to the accessions with these alleles.

2) Where the *DivSeek* initiative is seeking to spread a wide web over germplasm collections, the *Digital*

Seed Bank [15] an initiative of the Global Plant Council, seeks to drill deep into the biochemical mechanisms underlying the allelic diversity in genebanks. The idea is *obtain detailed information on the molecular and biochemical basis of genotype by environment interactions* to aid breeders in understanding how to harness and capture quantitative traits for yield and performance. The concept is that increasing our understanding of gene, protein and metabolite expression inherent in genebank accessions will provide breeders with an untold level of knowledge to advance food security.

Vision for the future – 2024

Collectively, we need every tool in our genetic resources toolbox to feed the world with nutritious, ample and sustainable food in the future. The global genebanks must be central to this effort and help facilitate the linking and access of information to specific accessions and then ensure that these accessions are available immediately when needed by breeders and other researchers. Genebanks are the hub of the wheel in partnership with researchers and breeders to provide the spokes that will support the small hold farmers of the world who make up the rim of the wheel allowing progress to move forward to ensuring a secure food supply. Funds will continue to be limited for genebanks and breeding programs hence the disciplines will need to work closely together to guarantee the most cost and time efficient means of generating the next generation of improved varieties. Coordination of multi-crop genomic programs must be accelerated to move the science forward as a mass rather than as individual disjointed projects to speed solutions and results not just to the large industrialized farming operations but also to smallholder farmers who are the most vulnerable suppliers for villages populated by people who cannot go to the next grocery store down the street. The genebanks of the world hold the genetic building blocks needed to feed the world and in partnership with breeders and researchers, these building blocks will underpin feeding the world.

In ten years, we need a major change in the way we do business. Publically web-based databases need to be designed, deployed and available freely to provide a one-stop shop for germplasm globally. Databases of holdings from all global genebanks must be linked in a user-friendly fashion allowing for distinct, different and evolving searches by multidisciplinary users who are looking for vastly different information from the databases. Databases must be interactive and set up in a way that they accommodate users as distinct as national and international genebank managers and curators, breeders, molecular biologists, biochemists, ecologists, social scientists, physical chemists, environmentalists, school teachers, policy makers, administrators, communication specialists, funders, farmers, and government agencies. Each has a different question and specific need that must be met by a robust global database system. This will likely be

15 http://globalplantcouncil.org/initiatives/digital-seed-bank

structured as many databases but they must be designed as a one-stop shop allowing the gathering of information on every accession in any genebank in the world meeting the search criteria.

Publically available annotated genetic sequences of all accessions in all genebanks world-wide will facilitate the narrowing down the number of accessions needing testing to discover the allelic combination for the challenge at hand. However such genomic information will only achieve maximum value when tied to specific trait information. With this association, traits, metabolic pathways and environmental-specific alleles will be available with a single click of a computer mouse. Cell phones will become more of an informatics tool than a communication device with plug in devices and apps for on farm data gathering and solution solving. An example developed by Douglas Weibel, University of Wisconsin, Madison is a tiny handheld cell phone attachment for multi-well disease diagnostics using the cellphone to provide energy to heat a multi-well plate where Recombinase Polymerase Amplification (RPA) reactions can then provide microbe specific disease diagnostics in 10 minutes. An app on the phone facilitates data conversion of the results into a reader-friendly form easily transmitted region wide in minutes via the phone.

Breeding limitations with the use of exotic and taxonomically distant germplasm will be alleviated with the generation, care and distribution of prebreeding populations in elite breeding lines as is being done with the GEM program described earlier. With whole genome sequences available for most crops, identification of the exact sequences and location of the exotic DNA in the breeding lines will facilitate use. In ten years multiple pre-breeding populations consisting of thousands of fully characterized useable accessions with traits of value should be available for at least the top 10 crops to expedite the use of exotic germplasm and the untold genetic treasures they hold. Coupled with this will be the routine field-based use of marker aided selection on handheld devices such as cell phones as illustrated above.

Perhaps the most important element in the future will be that all information on genebank accessions will have to be in the public domain in an accessions-specific manner as soon as it is developed. Increasingly, researchers and breeders will see that information shared in massive user-friendly publically transparent databases will greatly accelerate allele and gene discovery, development of new varieties and furthering science compared with individual closed source projects. Thus we will unlock the treasures currently in our genebanks to benefit human kind and feed the world.

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Response to "Could Genebanks be a Pot of Gold at the End of the Rainbow?": Status, Utilization and Vulnerability of Gossypium Spp. Germplasm Resources by Jane Dever and Richard Percy

Status, Utilization, and Vulnerability of Gossypium SPP. Gerplasm Resources

Jane Dever[16] and Richard Percy[17]

Introduction

The importance of conserving genetic resources for public use have been extolled by many, including Cary Fowler in the 2003 proceedings of this conference (Fowler, 2003). In my own crop, cotton, Campbell, et al., 2010, provide an elegant introduction to the importance of germplasm collections:

Plant genetic resources and germplasm collections represent a vital portion of the world's natural resources. Genetic resources and germplasm collections are reservoirs of genes and genotypes necessary to protect humankind of present and future generations from emerging crop diseases and vulnerabilities.

Preservation of the cultivars, landraces, and wild relatives of plant species provides a basic foundation to promote and sustain agriculture. It protects mankind from future, and many times unforeseen, crop vulnerabilities, thus protecting future food, feed, and fiber supplies. Preserved genetic resources will supply plant breeders, farmers, and other agricultural scientists with the genetic materials to develop new crop cultivars and hybrids that secure future food, feed, and fiber supplies.

The value of germplasm, already collected and conserved, is greatly appreciated with reference to agrobiodiversity and searching for new sources of useful genes in the future. In recent history, governments, individual organizations, and institutions have realized the importance of genetic resources and organized efforts for storage, maintenance, propagation and collection through explorations of many plant species and their wild relatives in gene banks or germplasm collection centers around the world. The importance of genetic resources was recognized at the intergovernmental platform under the Food and Agriculture Organization (FAO) of the United Nations as the "*common heritage of mankind*" which should be made available without restriction. The value of germplasm collections is now well recognized with the International Treaty on Plant Genetic Resources for Food and Agriculture implemented on 29 June 2004. The objectives of this Treaty are "*the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable*

[16] 1 Dept. of Soil and Crop Sciences, Texas A&M AgriLife Research, Lubbock, TX 79403. Corresponding author is J. Dever (jdever@ag.tamu.edu)
[17] USDA-ARS-CGRU, College Station, TX 77845

sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security"

The cultivated *Gossypium spp.* (cotton) represent the single most important, natural fiber crop in the world. In addition to its lint, the oil and protein portion of the cottonseed also represents significant economic value and are used in a variety of ways, including animal feed and industrial lubricants. Although the collection and introduction of cotton into the U.S. has a long and interesting history, the origins of organized, modern U.S. germplasm collection can be traced to collection efforts made in the early 20th century in response to a crisis similar to that which occurred in the potato, corn, and banana industries. The USDA, in response to devastation caused by the boll weevil, conducted several collecting trips to Central America and northern South America in attempts to find resistant germplasm (Percival et al., 1999). As a result, efforts were made to develop earlier maturing cultivars to avoid the devastating effects of the boll weevil (Smith, et al., 1999). During this same time, USDA also made organized efforts to introduce extra-long staple (ELS) *G. barbadense* cottons to create a cotton industry in the arid southwest. Cotton has been a crucial export for the US, but other nations have had a long history of production and have seen the necessity of collecting germplasm and maintaining it to protect the genetic stability of their industries. Today at least eight nations already have major collections of cultivated and wild-collected cotton and Gossypium germplasm. Information on global collections is summarized from Campbell, et al., review and interpretation.

Current World Collections

Although there are a few other cotton germplasm collections present in other countries of the world, these eight countries, France, India, China, Australia, Russia, Uzbekistan, Brazil, and the United States, represent the majority of the world's cotton germplasm resources. Campbell, et al., 2010, addresses collection numbers and members; maintenance and storage procedures; seed request and disbursement; funding apparatus and staffing; characterization and methodology; data management; and past and present explorations.

France

The French cotton germplasm collection at French Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) in Montpellier, France is a publicly supported agency that specializes in tropical and Mediterranean agriculture under the authority of the Ministry of Higher Education and Research and the Ministry of Foreign and European Affairs. This collection is a good example of ex situ conservation because cotton is not a domestically produced crop in France. CIRAD actively conducts research and maintains a collection for cotton produced in tropical and subtropical areas of the world. No additional germplasm explorations are planned for the near future (Campell, et al., 2010).

India

In India, cotton is a major agricultural commodity and a large part of the Indian economy. India represents the only cotton producing country that cultivates all four cultivated species (*G. hirsutum, G. barbadense, G. arboreum* and *G. herbaceum*) of cotton. The Indian cotton germplasm collection is maintained as a working collection by the Central Institute for Cotton Research (CICR) at Nagpur and Coimbatore and as a permanent storage collection at the National Bureau for Plant Genetic Resources (NBPGR) in New Delhi.

Since 1960, the Indian collection has grown with the establishment of the Indian Central Cotton Committee, the All India Coordinated Cotton Improvement Project, and the Central Institute for Cotton Research. In 1976, the Central Institute for Cotton Research was established with a mandate to function as National Centre for Cotton Genetic Resources collection, documentation and utilization and a new era began in augmenting global germplasm on cotton in India. Regular collection expeditions were organized by the National Germplasm Centre in collaboration with the National Bureau of Plant Genetic Resources (NBPGR) in various parts of the country. Plant explorations have covered a large part of India. The collection has also grown through exchange with the United States, France, Uzbekistan, and Czechoslovakia. FAO organized germplasm expeditions also provide opportunities to expand the germplasm collection.

China

China is the largest producer and consumer of cotton in world. The Chinese cotton germplasm collection is housed by the Chinese Academy of Agricultural Sciences in Beijing, Anyang, and Hainan Island. A working collection is housed at Anyang, a long-term collection at Beijing, and an *in vivo* collection of wild species at Hainan Island. Funding for maintenance of the collections is provided through the Chinese government through the National Key Technology Research and Development Program, the National Key Basic Research and Development Program, the National Science Foundation of China, the Ministry of Science and Technology, and the Ministry of Agriculture. Official germplasm seed requests within China are made to the Cotton Research Institute of the Chinese Academy of Agricultural Sciences. A Material Transfer Agreement (MTA) is required to distribute seed of requested germplasm. Seed requests from outside of China require a complex procedure for approval (Campbell, et al, 2010).

Australia

Cultivated cotton was first bought to Australia in the late 18th century but was only a small opportunity crop until irrigation schemes in the 1960s led to a rapid increase in area and production. Australia has a unique combination of heavy clay soil, numerous pests and diseases as well as climate factors which impact cotton production. A local breeding program has selected for adaptation to local conditions, with strong progress in yield progress due to breeding of 1.8% per year (Constable et al., 2001). Prior to 1980, Australian plant breeders acquired and maintained their own germplasm collections. However, the Commonwealth and State governments established a network of eight Genetic Resource Centers to conserve national germplasm collections of field crops and forages in the early 1980s. Over the past 15 years, these Centers have worked independently with limited coordination between host organizations primarily responsible for operating the Centers and maintaining the germplasm collections.

Currently, cotton collections in Australia resides in two places: 1) The Commonwealth Scientific and Industrial Research Organization (CSIRO Plant Industry), Narrabri, NSW, and 2) Australian Tropical Grains Germplasm Centre (ATGGC, www.dpi.qld.gov.au/auspgris) Biloela, Queensland (Campbell, et al., 2010).

Germplasm was extensively characterized in the past, but no current characterization work is being undertaken. There are numerous examples of germplasm utilization in Australia to face production vulnerabilities and develop new cultivars. MAR germplasm lines from the United States cotton collection were crossed to Australian accessions to develop bacterial blight resistance. Currently, all cultivars grown in Australia are resistant to bacterial blight. In addition, germplasm accessions from India and China have been crossed to Australian accessions to develop Fusarium wilt resistant cultivars (Campbell, et al., 2010).

Russia

Prior to the dissolution of the Union of Soviet Socialist Republics (USSR) in 1991, Russia was a primary center of cotton textile manufacturing for the cotton grown in Central Asia. Although over the course of history cotton has not been produced in Russia, the former USSR continues to represent a major worldwide source of cotton production and export. Following the establishment of independent republics, the former USSR cotton producing countries of Central Asia, including Uzbekistan, Turkmenistan, Kazakhstan, Tajikistan, and Azerbaijan, have continued producing and exporting large amounts of cotton.

The current Russian cotton germplasm collection, better known as the VIR collection, is housed at VIR in St. Petersburg. Somewhat unique to Russia, the VIR cotton collection contains approximately 100 colored lint accessions of all cultivated species from several different countries. The accessions produce cream-colored, golden, orange, reddish, brown, dark brown and green lint. The most interesting genotypes are wild perennial forms of G. *barbadense* from Peru that possess a whole spectrum of colored lint including pink and lilac-colored. Seed of germplasm accessions is freely available to researchers within Russia (Campbell, et al., 2010).

Uzbekistan

Cotton germplasm collections in Uzbekistan currently reside in three locations that include the Cotton Breeding Institute of Agriculture Ministry of Uzbekistan, the Institute of Genetics and Plant Experimental Biology at the Academy of Sciences of Uzbekistan, and the National University of Uzbekistan at Tashkent. In Uzbekistan, there is no facility available for cold storage of germplasm accessions. The collections are maintained under room temperature conditions. Insufficient funds are available to construct a facility with long-term cold storage capabilities. Consequently, there is a standard procedure for seed renewal every 8-10 years under forced self-pollination in the field (Campbell, et al., 2010).

Brazil

The Brazilian collection is maintained by the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) at the National Center for Genetic Resources. In 1974, the same year when CGIAR created the International Board of Plant Genetic Resources (IBPGR), EMBRAPA in Brazil created a research unit called the National Center for Genetic Resources (CENARGEN) whose basic mission was to coordinate the appropriate means of management of the genetic resources of the country. The base collection (COLBASE) of cotton germplasm collection is housed at EMBRAPA CENARGEN. The Brazilian collection at EMBRAPA is funded internally with resources appropriated by the Ministry of Agriculture. The long term maintenance of the collection is supported with EMBRAPA public resources (Campbell, et al, 2010).

In Brazil, there are about 4,361 cotton germplasm accessions of which 39 % are *G. hirsutum* and 35 % *G. barbadense.* The remaining accessions represent 26 diploid species and the other 3 tetraploid species. Brazil maintains 53 accessions of *in vivo* collections of *G. mustelinum* and 63 accessions of *G. hirsutum* var. marie-galante (mocó cotton), a racestock native to Brazil. During the last century, cotton was cultivated in two primary regions including the semi-arid northeastern states where perennial forms of *G. hirsutum* race 'marie-galante' were grown and the more humid states in the southeast where G. hirsutum latifolium was grown. At the end of the 1980's, economic and social changes occurring concomitantly with the introduction of the boll weevil, rendered cotton production non-viable in these areas. At the same time, agriculture in Brazil was expanding toward the Cerrado region (Brazilian savannah) and cotton was tested as one of the alternatives to develop crop rotation systems with soybean. The differences in climate and crop production systems compared to former cotton growing regions made it necessary to develop cultivars specific to the Cerrado, with higher yield potential and enhanced levels of disease resistance. To reach this goal, national public and private breeding programs made use of imported and local germplasm. As a result, the cultivated area expanded. The level of resistance to some of the most important diseases is insufficient, and germplasm screening efforts are necessary to identify new sources of resistance (Campbell, et al, 2010).

U. S. National Cotton Germplasm Collection

The early history of the cotton industry in the U.S. was, for the most part, a story of importation and adaptation of cottons from Mexico, Guatemala, and the tropics of the Western Hemisphere. By the 19th century there were two distinctive types of *G. hirsutum* cotton, with distinctive origins, being grown in the U.S. One type, known as green-seeded cotton, was from southern Mexico. The other dominant type, white-seeded cotton, had its origins in the central plateau of Mexico (Ware, 1936; Mauer, 1930). Although these cottons were grown extensively, no coordinated effort was made to maintain the original stocks or their progeny. Modern, systematic collection and preservation of cotton in the U.S. only began in response to the outbreak of the boll weevil in the 1880's (Percival et al., 1999). Three collection trips between 1902 and 1906 were responsible for the introduction of two cottons, Acala and Kekchi that would contribute significantly to the development of modern U.S. cultivars (Smith, et al., 1999). From these initial collecting trips and ensuing trips, federal, university and state experiment stations began to assemble the germplasm collections. Organization and centralization of germplasm activities was necessary to manage and increase cotton germplasm resources. Plant Introduction centers were established with the Agricultural Marketing Act of 1946 and a National Seed Storage Laboratory (now the National Center for Genetic Resources and Preservation or NCGRP) was established in 1958 for long term backup storage of germplasm. The International Board for Plant Genetic Resources (now Bioversity International) established a set of cotton descriptors in 1980 to serve as a data collection guide for data collection for the US and other collections (IBPGR 1980). Databases for the NPGS and the collection are managed online by the Germplasm Resources and Information Network. Information on the U. S. National Cotton

Germplasm Collection is summarized from a chapter prepared by Percy, et al., in press, The U. S. National Cotton Germplasm Collection – its Contents, Preservation, Characterization and Evaluation, in "World Cotton Germplasm Resources" edited by Ibrokhim.

Content and Contribution

The diverse germplasm present in the United States cotton collection has been critical for cotton breeding research focused on cultivar and germplasm development, as well as basic genetic, physiology, and production studies. Nearly 10,000 accessions covering 45 *Gossypium* species are maintained in the National Collection of *Gossypium* Germplasm and are distributed worldwide, making the collection the largest publicly available collection in the world. The collection is subdivided to seven different parts that consist of: 1) variety collection, 2) primitive landrace collection, 3) *G. barbadense* collection, 4) Asiatic (A-genome species) collection, 5) wild species collection, 6) genetic marker collection, and 7) a base collection (i.e. NGCRP) of all materials in parts 1-6 and new plant introductions (Percival et al, 1999). Parts 1-5 constitute the "working collection", which is routinely seed propagated and distributed.

A few examples of contributions the collection has made to cotton improvement efforts follow. The landrace and diploid species were found to possess useful genetic diversity (Dilday and Shave, 1976; Kohel 1978; Fryxell 1976), but most are photoperiodic and require conservation *in situ* or special care in greenhouses or winter nurseries. Germplasm accessions present in the United States collection were also used to develop trispecies hybrids that allowed breeders to transfer increased fiber strength genes from the D-genome diploid species *G. thurberi* to Upland cotton (Beasley, 1942). Several breeding programs, including the Pee Dee and New Mexico Acala, utilized these materials to develop cultivars and germplasm lines with increased fiber strength (Campbell et al., 2009).

Another very interesting use of the collection occurred when cottage industry spinner and weaver, Sally Fox, was working with USDA scientists to screen wild cotton for host plant insect resistance. She turned brown and green lint accessions into cotton varieties 'Coyote' (PI 601707; PVP 8900169), 'Buffalo' (PI 576174; PVP 9400039), 'Green' (PI 601708; PVP 8900170), and 'Palo Verde (PI 576175; PVP 9400040). In addition, recently, *G. longicalyx*, a wild, diploid species, was used to transfer reniform nematode resistance into tetraploid *G. hirsutum* cotton (Robinson et al., 2007). This utilization of wild germplasm provides breeders a real opportunity to develop new cultivars with reniform nematode resistance and environmental adaptation. It also represents a tremendous response from the cotton community to develop resistant varieties when an alternative control, aldicarb, was no longer available.

Collecting and Exchange

Although domestic upland (*G. hirsutum)* cotton dominates world production (~95%), it is generally accepted that its genetic diversity is very low (Abdalla et al. 2001; Wallace et al. 2009; Xu et al. 2002; Multani and Lyon 1995). Various bottlenecks and restrictions to genetic variability have occurred during the breeding history that have led to its current low diversity and now limits future cotton improvement (Ulloa et al. 2007; 2009). Our germplasm collections have historically served as reservoirs, providing useful variation for disease and insect resistance, fiber quality improvement, and resistance to environmental stress. Collecting and exchange efforts are necessary to maintain and increase the genetic diversity of our collections (Ulloa et al. 2009, 2013). Recognizing the importance of germplasm diversity, the USDA opened its Plant Introduction Office in 1898 and sponsored numerous plant exploration trips and germplasm research efforts in the early to mid-twentieth century (Percival and Kohel, 1990). The acquisition of germplasm through collection has become the subject of extensive negotiation with host countries, and often includes the topics of benefit sharing and agreements on proprietary rights of host countries to products originating from germplasm. The latter topic has become a major stumbling block to collecting for the U.S., National Cotton Germplasm Collection. In the past, the collection has only acquired germplasm that can be distributed free and clear of proprietary obligations, and the collection remains committed to this policy. Careful bilateral negotiation with individual nations, assuring mutual benefit, has led to limited germplasm acquisitions by the US national collection in the latter half of the twentieth century. Since 1985 twelve acquisition trips have been made by US scientists to collect germplasm. Ten of the trips were used for *in situ* explorations, while two of the trips were conducted to exchange germplasm with India, China, Russia, and Uzbekistan respectively (Wallace et al., 2009). Continued collection and germplasm exchange is essential to address gaps in individual collections worldwide and to conserve *ex situ* germplasm threatened by development (Campbell et al. 2010).

The two most recent collecting efforts that resulted in germplasm acquisition by the U.S. collection were to Mexico in 2004-2006 and to Puerto Rico in 2013. Mexico encompasses the species range of several diploid cotton species, and Mexico-Guatemala is the recognized center of origin of *G. hirsutum,* the most widely cultivated species in the world. Since the first collection-expedition trips were made in Mexico, the *in situ* survival of Mexican cotton germplasm has been threatened with increasing human population, modernization of agriculture and urbanization. New roads and population growth continue to increase. At this point, one species (*G. aridum*) of the subsection *Erioxylum* appears not to be threatened, probably because of the great diversity (botanical and geographic) encompassed by this species (Ulloa et al., 2006). However, some of the most recent collected and nondescribed taxons (e.g., US-72) or ecotypes of the *G. aridum* species (Ulloa et al., 2006, 2013) may be in the process of becoming extinct in the wild. In addition, the D_8 *G. trilobum* species is almost extinct or already extinct. The natural habitat of this species has been replaced by intense and extensive agricultural production of guava (*Psidium* spp.).

According to information obtained from local sources, eradication of naturally occurring landrace, feral, and dooryard was attempted in areas of southern Mexico in the 1980's in efforts to remove perceived insect reservoirs Apparently all attempts at commercial cotton production since then have been abandoned. No commercial fields of cotton were encountered during expeditions between 2002 and 2004 in the central and southern part of Mexico (Ulloa et al., 2006). Currently, not counting the Northern cotton production regions of Mexico, the diversity of the *G. hirsutum* is limited to feral plants that occur opportunistically in waste areas and as occasional home garden plants maintained as a novelty by rural peoples or village residents (Ulloa et al., 2006).

Due to its relative proximity to the U. S. and its status as a U.S. territory, Puerto Rico was a target of opportunity for recent collecting efforts. Puerto Rico was revisited in the most recent germplasm collecting effort by the U.S. National Cotton Germplasm Collection in 2013. Dooryard cottons were in low frequency on the island and may be declining as cotton products and substitutes become more available for purchase. One resident extolled the virtues of natural cotton because of lack of chemical use on them, and she demonstrated how they were propagated via cuttings, which may be indicative of a hard seed coat frequent in wild cottons.

Phenotyping and Characterization

Phenotypic characterization of the national collection has historically served dual purposes. Until the very recent past (when molecular tools became available), phenotypic descriptors were the primary means of describing the diversity contained in the germplasm collection and rationally classifying that variability. The second role of phenotypic descriptors was to assist breeders and others in identifying germplasm of interest in genetic improvement efforts. Within the collection, a goal has been set to routinely characterize or re-characterize approximately 1,000 accessions (or a tenth of the collection) annually in the cotton winter nursery (CWN), or in local fields or greenhouses at College Station, TX. Although the photoperiodism of a large portion of the collection requires that it be renewed in the tropically located CWN, To date (2011-2013), standardized descriptors and digital images have been collected on over 4,900 cotton producing accessions planted at the CWN and in the field at College Station, TX. These images are in the process of being uploaded into the CottonGen database (www.cottongen.org) for pairing with descriptors for optimal use by the cotton community. The high resolution library or "virtual herbarium" created by the use of high resolution cameras to produce 'virtual' voucher specimens enables an access and ability to examine the morphological variation within the genus that was previously unattainable with classic herbarium specimens. It is hoped that the digital image library promotes standardization of descriptor data and image creation by cooperating groups and collections, thereby promoting a greater ability to characterize the diversity within *Gossypium*, address gaps in the U.S. and other collections and effectively share and backup germplasm between collections. Although the U.S. National Cotton Germplasm Collection tries to set standards and methodologies for characterizing the germplasm collection through its internal efforts, it also recognizes and encourages cooperation from the research community in this task. Due to the volume of accessions available for characterization, the finite resources of the collection, and the impact of genotype x environment interaction on many phenotypic traits of interest, a unilateral effort to collect descriptor data is not considered desirable. Research community based, collaborative efforts offer an attractive way to collect relevant data and make it widely available. One such effort has been ongoing by Texas A&M AgriLife Research, Lubbock, TX since 2005. Seed of accessions from the US National Cotton Germplasm Collection at College Station, TX are obtained and planted in the greenhouse at Lubbock for seed increase. In conjunction with seed increases, phenotypic descriptors of various *Gossypium* species were recorded and documented using digital photography.

Evaluation efforts

The screening and evaluation of the national collection for traits such as disease, insect, and environmental stress resistance are beyond the capacity and resources of the national collection to achieve, and necessitate research community efforts and participation to occur. Despite this fact, the collection in recent years has tried to move from a passive supplier of germplasm resources to an active participant in germplasm disease and insect resistance screening and evaluation efforts. The collection has a long history of being the subject of evaluation efforts by the research community for biotic and abiotic stress resistance. In fact the origins of the collection are intertwined with the entry of the boll weevil into the United States in the 1890's and the search for a source of_host plant resistance to that pest. Numerous evaluations have been conducted on the collection for phenotypic characteristics of agronomic importance. Seed protein (Kohel, 1985), seed oil (Kohel et al., 1978), seed gossypol (Dilday and Shaver, 1976), boll weevil resistance (Jenkins, 1978), Cercospora leaf spot and Verticillium wilt (Jenkins and Parrott, 1978), root knot nematodes (Shepherd, 1983), etc. were studied on portions of the collection. As of 1986, over 200 accessions of the collection had been reported to carry resistance to one or more pests (Jenkins, 1986). Prior to 2000, over 320 accessions of the collection had been screened for resistance to pink bollworm (*Pectinophora gossypiella* Saunders); 471race stocks of *G. hirsutum* were screened for resistance to root knot nematode (*Meloidogyne incognita*) and resistance found in 18 lines (Shepard, 1983); and 256 accessions had been screened for elevated floral gossypol levels, just to list a few examples. Recently, eleven evaluations of collection germplasm for disease, insect, and nematode resistance were reported in a status report of U.S. cotton germplasm in 2009 (Wallace et al., 2009).

The Cotton Breeding Program at Texas A&M AgriLife Research Center, Lubbock, TX began in 2005 to screen accessions from the working collection for resistance to pest thrips (Thysanoptera: Thripidae). Thrips were ranked as the number three pest of U. S. cotton in 2012 (Williams, 2012). By 2013, 516 accessions from the active collection of the U.S. National Cotton Germplasm Collection had been screened. Resistance to thrips was identified in *G. barbadense* accession TX110 (PI 163608) in the first year of screening (Arnold, et al., 2007). A series of studies conducted through much of the 20th century identified, confirmed and characterized thrips resistance in *G. barbadense*. Studies in this progression include: the discovery of resistance in glabrous Egyptian cotton cultivars and the conclusion that resistance is most likely due to a thicker leaf epidermal layer on lower sides of leaves allowing cotton seedlings to tolerate more thrips feeding (Wardle and Simpson, 1927).

Interspecific hybridization between resistant *G. barbadense* accession, TX110 and two unreleased elite lines from the Lubbock Texas A&M AgriLife Research Cotton Breeding Program was used to begin a cultivar development project for organic cotton production supported by NIFA Organic Research and Extension Initiative. Selections for thrips resistance and day-neutral flowering habit were made in the segregating F_2 plots, and this process continued for five years. Resistance has been carried to the F_5 and F_6 generations in many individuals, and day neutral flowering habit and favorable agronomic traits have been improved.

In another ongoing project funded by USAID and USDA to identify sources of resistance to Cotton Leaf Curl Virus (CLCuV), germplasm resources were made available through the US National Cotton Germplasm Collection. The ready availability of accessions from the collection, combined with winter nursery seed increase capabilities, GRIN database information and especially the recent addition of standardized descriptor data and digital images, made possible a rapid coordinated CLCuV screening program. CLCuV is a major threat to cotton production in Pakistan and parts of India and has been reported in cotton producing countries in Africa, as well as China and Uzbekistan. This project to identify sources of resistance to CLCuV, helps not only countries such as Pakistan where the virus is already a problem, but also makes resistant germplasm available, should CLCuV become a threat to cotton production in other countries. This project has served as a model for a germplasm evaluation effort that serves the germplasm collection as well as the research community. In addition to identifying resistant sources to CLCuV for future cotton improvement efforts, the project made possible the seed renewal of numerous accessions of the collection under controlled conditions and the characterization and digital imaging of these same accessions.

Another current effort involves evaluating germplasm resources to identify lines with physiological and morphological traits that can improve water use efficiency and tolerance to extreme temperature and drought. The decline in water reservoirs and aquifers in many regions, combined with climate change and the unpredictability of precipitation during the growing season, has stimulated efforts to identify germplasm resources that can minimize the elevated production risks associated with crop water deficits. Untapped genetic variability or diversity for plant and root morphologyarchitecture types is present in germplasm resources but lacking in modern commercial cultivars (Ulloa et al., 2007; 2013). However, methods of morphological or phenotypical characterization have progressed slowly in the last 30 years (White et al., 2012). Currently, germplasm from the USDA-ARS Cotton

Germplasm Collection at College Station TX are being used by the USDA-ARS Cropping Systems Research Laboratory, Lubbock, TX to initiate this phenotypical characterization. Specifically, drought responses are being examined on selected germplasm (diverse core reference set of cotton accessions) from an ongoing diversity study within the USDA-ARS College Station, Texas, group. Physiological and biochemical plants responses such as photosynthesis and CO_2 rates, stomata conductance, and osmotic adjustment are monitored under heat and/or low-temperature stress conditions. In another project to screen the germplasm collection for drought tolerance, 400 accessions have been evaluated for variation in associated growth parameters by the Cotton Breeding Program at the Texas

A&M AgriLife Research Center, Lubbock, TX.

Genotyping

Molecular tools provide the means to characterize underlying genetic diversity that is not measurable through classical phenotypic descriptors (Tanksley and McCouch, 1997). With the advance of DNA marker technologies, it is now possible to characterize *Gossypium* germplasm not only phenotypically at the levels of whole plants but also genotypically at the levels of whole genomes (Kohel and Yu, 2001). In general, cotton lags behind other major crops in genomic tools that are available for effective manipulation and exploitation of beneficial genes otherwise buried in *Gossypium* germplasm collections. The first molecular maps for cotton were based on the cumbersome and expensive restriction fragment length polymorphism (RFLP) technology that requires large amounts of genomic DNA and generation of radioactive probes physically disseminated to the research community as plasmid or phage clones (Reinisch, et al., 1994; Shappley, et al., 1998). New DNA marker technologies are used to coordinate the systematic characterization and simultaneous comparison among various research efforts involved in cotton diversity analysis and genetic resource preservation.

Databases

Utilization of germplasm collections is intimately tied to knowledge of the genetic diversity in the collection and accessibility of that knowledge. Quality of easily accessible electronic databases is essential to disseminate information to the community. CottonGen (www.cottongen.org, Main, et al., 2012) is a curated and integrated web-based relational database providing centralized access to publicly available genomic, genetic and breeding data for cotton. CottonGen was initiated in 2011, replacing USDA-ARS curated Cotton DB, and combining information from other cotton databases operated from Clemson University and University of Georgia. While consolidation is positive, issues such as descriptor standardization and non-uniformity in accession names are highlighted. A steering committee was formed, including a mix a USDA and state university representatives with members representing private industry contributing to the funding of CottonGen. CottonGen was set up to handle digital images supplementing descriptors. Approximately 12,000 images are currently online, with plans to add another 10,000 in 2014.

Vulnerabilities

Plant breeding programs have benefited from genetic resources and germplasm collections to develop improved genotypes with significant gains in yield for commercial production. This has also unintentionally narrowed the genetic base and increased genetic vulnerability of many of the world's most important crops, including cotton. Cotton is fortunate to have several good global collections, but this also increases the challenge of describing the variability in collections. Only when adequately described does the collection reach its potential for crop improvement. Molecular techniques hold promise, both for uniformly characterizing accessions and facilitating introgression of native traits into public cultivars. Proper phenotyping is still an important component and resource-limited, especially without cooperation of community based collaboration.

The state of cotton germplasm collections are generally good, but face challenges. These include, but are not limited to, loss of *in situ* genetic variation due to development and human activities, aggravated by inaccessibility of *in situ* sites and political barriers to collecting. In developing countries resources for germplasm preservation in collections often remain inadequate, yet present international treaties and proprietary attitudes toward germplasm interfere with abilities to share and preserve on a global scale. Although redundancy within collections is not desirable, germplasm exchange and backup of materials between collections should be promoted. Nationalistic concerns can interfere, and political instability in areas where some native cotton resides can complicate collection efforts. Preservation of *in situ* germplasm preserves should be attempted when possible however in areas being developed for commercial production, wild species are viewed as insect or pest hosts.

It is indeed true that germplasm banks are not museums. One risk to cotton is operation of the Cotton Winter Nursery (CWN) in Mexico. The collection, as well as public breeders, utilizes this resource not only to advance generations, but to increase seed of wild accessions or wide crosses that cannot be easily produced in the northern hemisphere. In the very few crops that coexist with intense commercial adoption of transgenic traits, risk of even very low amounts of unintentional contamination in CWN host countries that disallow the technology is politically averse. Low levels of unintentional presence of transgenic traits may also unnecessarily threaten effective operation, exchange and utilization of affected germplasm banks. Strategies to avoid hindering utilization of genetic resources should be developed so that the National Crop Genetic Resources Program mission to "acquire, evaluate, preserve and provide a national collection of genetic resources to secure the biological diversity that underpins a sustainable U.S. agricultural economy through diligent stewardship, research and communication" can be realized.

Summary Recommendations

Campbell, et al., 2010 summarized general concerns regarding the global cotton germplasm collections that are translatable to other collections: 1) long-term financial support for germplasm conservation and storage infrastructure improvements, 2) future germplasm exploration and international exchange, 3) data collection guidelines and uniformity, and 4) database storage and accessibility. Also emphasized is the importance of international collaboration to protect, secure, and evaluate the global cotton germplasm resources. Without global, collaborative efforts to collect, protect, and secure cotton germplasm, the rarest and most unique cotton germplasm resources are vulnerable to extinction. The United States should ratify the International Treaty on Plant Genetic Resources for Food and Agriculture to ensure access and exchange of global germplasm resources important for adapting crops to environmental change.

Given finite and sometimes constricting resources; efficiency and effectiveness in preserving, characterizing, and evaluating the collection's contents becomes imperative. One means of increasing the efficiency and effectiveness of the collection has been to enlist the research community in characterizing and evaluating the collection. Currently there are dynamic cooperative efforts to evaluate the collection for drought, heat, and other environmental stresses associated with global climate change. Efforts to find resistance to biotic stresses within the collection continue, as do efforts to identify positive variation within the collection for agronomic and fiber quality characteristics. The development of genetic marker technology greatly increases the ability to investigate the genetic variation of the collection and offers needed means to manage the collection's contents through identification of redundancy, misclassification, introgression, and sources of unique variability within the collection.

Cooperative efforts within the research community to characterize and evaluate the collection, while very effective, could be replicated at an international level with greater impact.

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Response to ***"Could Genebanks be a Pot of Gold at the End of the Rainbow?"***: Assuring the Viability and Accessibility of our National Germplasm Collection by Theresa Podoll , Frank Kutka & Steve Zwinger

Assuring the Viability and Accessibility of Our National Germplasm Collection

Theresa Podoll[18], Frank Kutka, Steve Zwinger

The NPSAS Farm Breeding Club is working to address member priorities for diversifying organic cropping systems through the identification of alternative crops, new crop varieties well suited to our region's growing conditions, and cover crop seed varieties. Diversification reduces demands on non-renewable resources, provides enhanced ecosystem services, and is a risk reduction strategy. There is increasing interest in nutrient dense foods and foods addressing rising dietrelated illnesses. Providing the crop diversity and genetic diversity within those crops necessary for a resilient agriculture in the face of climate change is a high priority for the FBC.

Our public germplasm collection, the National Plant Germplasm System (NPGS), is a critical source of valuable germplasm necessary to the fulfillment of the mission of the FBC. Germplasm with desirable traits can be researched, accessed, and trialed. Accessions with suitable agaronomic and quality traits can be taken to seed increase and made available to farmers or be incorporated into breeding and plant variety improvement efforts.

Access to Observational Data

There have been substantial improvements in the search-ability of the GRIN database as well as the amount of information available for various accessions. The FBC has made frequent use of the ability to search the database using various traits of interest, increasing the likelihood of trialing the most suitable germplasm to our location and needs. There is increasing observational data, including information on where that observational data was collected, as well as photographs of accessions. Ongoing submissions of observational data and the collection of photographs should be strongly encouraged as a responsibility of those accessing the germplasm in our national repositories.

Historical, Unavailable & Inactive Accessions

Some accessions are listed as "historical" or "unavailable accessions" with the caveat that the accession "may be available from the original donor." There are links to the original records for the "inactive" germplasm that "is maintained in the GRIN database for historical reasons." GRIN goes on to state, "The germplasm may have been duplicated by another accession or removed from the collection because it could not be

[18] Northern Plains Sustainable Agriculture Society's Farm Breeding Club, Management Team. Corresponding authors are F. Kutka and S. Zwinger.

maintained." You are invited to contact the ARSbased, Plant Exchange Office "to determine if the germplasm is available from another source." We have requested accessions only to be informed that the germination rate was so poor that no seed could be sent out. One regionally relevant native variety of dry bean was deemed "not viable" and became another "historical, unavailable accession." In this case we were told that the seed would remain in storage in the hopes that DNA techniques would one day be able to bring the variety back.

This begs the question of funding for seed increases of less frequently requested material, protocols for storage and maintaining viability, and protocols for the handling and storage of seed that is no longer viable.

Phytosanitary Concerns

Another source of concern for our farmer cooperators and researchers alike is the inclusion of warnings concerning the potential for the transmission of plant diseases, particularly viruses. The warnings are not made known when placing your order; a slip of paper detailing the warning is included with the shipment. This has caused the FBC problems in placing on-farm participatory trials, given the potential for importing new viruses that may affect other cash crops being grown by our farmer cooperators.

Phytosanitary mechanisms, grow-out locations and isolation protocols from potential sources of infections, including commercial crops being grown nearby, should be reviewed and improved where possible.

Quality Control, Order Fulfillment, and Response Time

Poor germination rates and seed quality are an issue for maintaining the quality of research. It is often difficult to trial varieties and distinguish between seed quality vs. genetic suitability and performance differences between accessions. First year results are easily skewed due to poor seed quality.

We have noted vast differences in the response times to and fulfilment of germplasm requests across the various repositories. Our team has noted a decreasing percentage of accessions requested being fulfilled, increasing response time and delayed shipments, and an increasing delivery failure rate in recent years. It is hard to discern the source of these difficulties; it may be there are simply more requests being made of some repositories and for certain accessions. Some of the feedback we have gotten from curators relates to their funding for staff, staffing turnover, as well as institutional hiring protocols that slow the hiring process, making it difficult to handle turnover and maintain appropriate staffing during high labor demand seasons.

Best Management Practices

In the FBC's experience the gold standard for responsiveness and percentage of fulfilled requests, is set by the National Small Grains Collection including Barley and Wheat Genetic Stocks (NSGC), in Aberdeen, Idaho, followed closely by the North Central Plant Introduction Station in Ames, IA, and the Western Regional Plant Introduction Station in Pullman, Washington. Our FBC team believes that the vast differences in performance across the various repositories prescribes the need for identification of best management practices (BMPs) being utilized by the highest performing repositories to be codified and adopted throughout GRIN. Certainly various crops will require crop-specific handling and protocols. However, there may be BMPs that can be duplicated across or within certain segments of the network. This will help to insure the integrity of the accessions within the collection as well as the accessibility of the germplasm for research and development needs.

Funding

Given the FBC's experiences with the National Plant Germplasm System and the incredible reach it provides us in achieving our goals, we call for funding the NPGS and GRIN at levels that will maintain their integrity and rectify some of the problems related to budgets and staffing that seem to be increasing in recent years. Few farmers in history have had the opportunity to choose among the seeds of the world when working to improve their lives. This outstanding service should be maintained and augmented to the benefit of ours and future generations to come. The flexibility and speed with which we will need to address oncoming issues in agriculture demand nothing less.

Response to *"Could Genebanks be a Pot of Gold at the End of the Rainbow?"*: Balancing Ex-Situ Conservation Efforts by Joy Hought

Balancing Ex-Situ Conservation Efforts

Joy Hought[19]

Organizational Background

Native Seeds/SEARCH is a 30-year-old nonprofit seed bank serving the southwest region. Its mission is to conserve, distribute and document the diverse crop varieties (and their wild relatives) of the American Southwest and northwest Mexico. We currently maintain nearly 1,900 landrace varieties of maize, beans, squash, and a small number of non-food crops such as traditional Native American fibers and dyes. Each of these varieties is valuable for their genetic diversity, high nutrition, and adaptation to arid land and low-input conditions.

The collection is housed in a modern seed storage and office facility in Tucson; accessions are regenerated on a rotating basis on our 60-acre, minimum-input, irrigated farm in Patagonia, Ariz. Surpluses are sold or distributed for free in packets and to a limited extent as bulk seed. In 2012, we distributed nearly 50,000 seed packets, representing over 500 rare varieties—through our Native American Free Seed program, our retail store in Tucson, and our print and online catalog.

The material in our collection has tremendous potential for use in organic agricultural systems, and it is our vision going forward to develop a more robust integration of ex-situ and in-situ conservation efforts in connection with crop improvement research.

Conservation and Development Goals

Our long-range goals are to:

-Rationalize our collection to focus on unique diversity, and prioritize seed increases of useful cultivars.

-Target the collection and exchange of arid lands adapted varieties from similar bioregions, and explicitly address climate change adaptation in our region's agricultural landscape.

-Increase focus on documentation and sharing of agronomic and cultural practices.

-Improve seed access and use between Native American and underserved communities.

-Improve the use and relevance of landraces among modern farmers through collaboration with organic plant breeders.

-Establish a participatory breeding and research network to assess and improve agronomic traits of targeted crops. (A number of landrace beans and squashes, for example, would benefit from systematic evaluation and selection for improved disease resistance, tolerance to organic inputs, and yield.)

-Serve as a research center for development of arid-adapted crops.

[19] Director of Education & Outreach, Native Seeds/SEARCH

-Support community-led efforts to manage crop diversity, such as by providing incentives to promote distributed conservation

Challenges

Given that our accessions were originally derived from a number of sovereign nations, in order to move toward these goals we will have to navigate a few challenges, including balancing the need to maintain the genetics of landrace populations as they originally came to us, versus proactively adapting and improving them for suitability in contemporary sustainable systems.

We want to make material accessible to researchers while ensuring appropriate intellectual property protections and benefit- sharing for indigenous communities. While NS/S serves non-native as well as native communities, we will need to move cautiously in identifying applicable stakeholders and obtaining informed consent, in an era when seed is emerging as a central issue of tribal sovereignty in the United States. The deployment of GE crops on or near tribal lands has galvanized much of this effort. Tribes in Minnesota, Hawaii, and New Mexico and others have, and legislators in New Mexico have recently proposed a bill to support training in monitoring genetic purity of indigenous seeds. Among tribes there is also a legacy of distrust of the USDA and of crop scientists, which have in the past both denigrated and appropriated indigenous knowledge. Finally, there are substantial cultural and philosophical differences around the function of seed, the aims of plant breeding, and appropriate technologies. Representatives of other tribal seed banks have expressed that do not view their seed as “decomposable” units, but whole plants.

Finally, I have observed that Native American seed collections are hesitant to share their material more freely specifically as a consequence of the loss of public commons around seed. People fear that sharing will inevitably result in privatization, and aren't aware of any other space for it to be shared into. Policy support for the revival of public-interest breeding, and increased awareness that many breeders are allies, would engender more free exchange of germplasm from this category of sources.

Keynote Paper # 4: "Fast Food: Supporting Farm Innovation in a Changing Climate" by Kathy Jo Wetter & Pat Mooney

KATHY JO WETTER is the Research Director at ETC Group, an international research and advocacy organization. ETC Group monitors corporate concentration in the ever-expanding sector once known as "life sciences" and tracks emerging technologies and their impacts, or potential impacts, on marginalized communities. For more than 13 years, Wetter has contributed to ETC Group's research and analysis on the ownership, control, social and environmental impacts of technologies, including nanotechnology, agricultural biotechnologies (e.g., seed sterilization and so-called climate ready crops), synthetic biology and geoengineering. She holds a Ph.D. from the University of North Carolina at Chapel Hill.

Fast Food: Supporting Farming Innovation in A Changing Climate

Pat Mooney[20] and Kathy Jo Wetter[21]

Commercial Seed from a Global Perspective: First Link/Kink in the Food Chain?

I. Concentration and Control: Seed's primacy in the food chain inextricably links seed security and food security. Agribusiness, however, views seed – not as a means of food production or an end product for consumption, but – as a vehicle for delivering proprietary technologies. In industry's view, the seed sector is moving "from a production/niche product marketplace to a technology distribution marketplace."[1] In this scenario, seed becomes like a cell phone or laptop: a container for holding a patented, upgrade-able "operating system."

One way to understand trends that are influencing – and will influence – seed security is to understand the agrochemical industry. The world's top 10 agrochemical companies control 94.5% of the $44 billion global market while the leading 3 companies account for more than half of the market.[2] The six dominant companies [Syngenta (1), Bayer (2), BASF (3), Dow (4), Monsanto (5) and DuPont (6)] command 76.4% of the global market. With BASF being the only exception, the other five companies rank among the top 10 global seed companies. Nevertheless, BASF – though not a significant seed retailer – has formed extensive plant breeding partnerships with the other major seed companies.

How great is the influence of agrochemical companies on the seed companies? The world's 10 top seed companies control 75.3% of the $34.5 billion global commercial seed market while the leading 3 companies (Monsanto, DuPont and Syngenta) control 54.3%. Five companies [Monsanto (1), DuPont (2), Syngenta (3), Bayer (7), and Dow (8)] have 60.7% of the market. Again, BASF – although not ranked among the top 10 seed companies – is closely connected through research agreements with the other leading companies.

The critical point for seed security/food security is that these 6 companies also account for 76% of global private sector agricultural R&D.[3] Although Monsanto and Syngenta (especially) have extensive investments in vegetables and fruits, the dominant 6 overwhelmingly focus on a dozen major crops with 45% of the research targeted to one crop – maize.[4] Among the largest seed enterprises, the average cost of developing new GM plant variety is estimated to be $136 million.[5] Conventionally bred plant varieties

[20] Executive Director; Action Group on Erosion, Technology & Concentration (ETC Group)
[21] Research Director, ; Action Group on Erosion, Technology & Concentration (ETC Group)

generally reach the market at a cost of around $1 million. [6]

Looking through the other end of the telescope, the commercial seed market directly contributes to just a small percentage of global food production – a fact that Monsanto spokesmen repeatedly (if disingenuously) emphasized during the company's short-lived investigation by the US Department of Justice's Antitrust Division. [7] Though the situation varies by crop and region, 80% - 90% of the seed planted by farmers in the global South comes from the "informal sector" – that is, farm-saved seeds (including seed exchange with neighbouring farms and seed sales from local markets or seed fairs). [8] Just 10% - 20% of seed requirements in developing countries is met by the "formal sector" – that is, seed companies, government seed sources or other institutions. Whether for economic or environmental reasons, the vast majority of smallholder producers do not use either agricultural chemicals or synthetic fertilizers and are not directly affected by these markets. Since the overwhelming majority of crop and livestock production is grown and consumed within national borders – ETC Group's estimate is 85% [9] – the direct influence of multinational traders, processors and retailers has been limited.

However, the scene is changing – rapidly and significantly – with the shifting commercial focus to emerging markets. Recent changes in subSaharan Africa and South and Southeast Asia are especially noteworthy:

-DuPont Pioneer has bought Pannar Seed, South Africa's biggest seed company, which does business in more than a dozen countries on the continent.

-Syngenta announced in 2012 that the company would invest $500 million and hire 700 people to pursue markets in Ghana, Ethiopia, Tanzania, Mozambique, Ivory Coast, Nigeria and Kenya.[10]

-Vilmorin acquired a 61% stake in Bisco Bio Sciences Pvt. Ltd., an Andhra Pradesh-based company selling hybrid seeds of maize, rice, bajra and jowar (millets), sunflower and sorghum; Vilmorin also acquired vegetable seed seller, Delhi-based Century Seeds.

-Enza Zaden, a Dutch vegetable breeding company that operates in more than 20 countries, created a new subsidiary, Enza Zaden India Pvt. Ltd. based in Pune, which focuses on new hybrid vegetable varieties for the local market. Enza Zaden already has subsidiaries in Indonesia, China and Tanzania.

-Syngenta became the majority shareholder of Belgium-based Devgen NV, which produces rice seed for markets in India and Southeast Asia. Devgen's subsidiary in India, Devgen Seeds and Technologies Pvt. Ltd. (Hyderabad), sells hybrid rice, sorghum, pearl millet and sunflower seed. Devgen also sells hybrid rice in the Philippines and Indonesia. Devgen's five-year R&D agreement with Monsanto related to biotech traits in rice ended in 2011 and allows Devgen to use the results of the partnership.

-Arcadia Biosciences, Inc. signed an agreement with Bioseed Research India Pvt. Ltd. (Hyderabad) to develop tomatoes with longer shelf life. India is the world's fourth largest producer of tomatoes.

-Evogene Ltd. and Rasi Seeds (Tamil Nadu, India) are collaborating to develop hybrid rice with increased yield and drought tolerance. Rasi Seeds will integrate genes licensed from Evogene into rice and test them in field trials. The agreement allows Rasi Seeds to commercialize the resulting hybrid rice in India and South-East Asian countries. Evogene will receive milestone payments and royalties based on sales.

-Genomic analysis company, California-based Affymetrix, Inc. signed an MOU with BGI (China), "the world's most prolific sequencer of human, plant, and animal DNA,"[11] to develop and commercialize a portfolio of plant, crop and livestock microarrays for genotyping analysis for breeding and traceability applications. The collaboration uses data from the 1000 Plant and Animal Reference Genomes Project, initiated by BGI in 2010.

-Vilmorin acquired Link Seed, South Africa's fourth largest seed producer. The majority stake (80%) gives Vilmorin a foothold in the local market for corn and soybeans as well as emerging markets of South and East Africa.[12]

Mergers, acquisitions and partnerships with seed companies rooted in the global South are just a part of the seed industry's business strategy, however. In the seed industry's view, proprietary seeds can't turn a profit (anywhere) without "enabling regulatory environments," which includes enforcement of intellectual property (IP). While no one expects the developing world to accept patents on plants "in the near future,"[13] there is coordinated pressure, particularly on Africa and China, to enforce IP in agriculture by adopting and making operational the 1991 Act of the International Convention for the Protection of New Varieties of Plants (UPOV 91), which prohibits the exchange of protected varieties between farmers (including through sale, barter or gift) and restricts the practice of farm-saved seed.[14] Even in cases where some amount of seed- saving could be allowed by subsistence farmers under UPOV 91, saving seed "is not something we in any way, shape or form want to encourage," argues Bernice Slutsky, vice president of science and international affairs for the American Seed Trade Association.[15]

However, constraints imposed by the commercial need to meet intellectual property criteria (bred varieties must be distinct, uniform and stable) dangerously undermine the diversity needed to respond to changing conditions, while constraints imposed on growers by intellectual property restrictions do not allow varieties to adapt to/evolve within local conditions over several growing seasons. Instead, the industrial system freezes diversity by insisting that farmers purchase and plant old ("*rigor mortis*") varieties each year.

Beyond the customary means of protecting intellectual property (enforcement of patents, PBRs), extensive cross-licensing and other "strategic alliances"[16] among the seed industry's biggest players have become the "lifeblood" of seed breeding and have created, in effect, a seed industry cartel in the historic understanding of the term (i.e., 4 or fewer enterprises that control 50% or more of sales in a given sector with innovation stagnation as a result).[17]

But even that level of concentration is dangerous for the world's food supply, particularly in the era of climate change. Extreme weather events – including unpredictable short- and long-term changes in temperature, precipitation and shifting and mutating pests and diseases – mean that no one can be certain what will grow where or when. In order to adapt quickly, producers need immediate access to massive diversity – and to the experience of other producers.

ETC Recommendations for Policy/Action: Concentration is a problem for global crop diversity, but seed/agrochemical cartels – now targeting markets in the global South – exacerbate the threat. To keep food on the table, barriers to farmer innovation, including exclusive monopoly on vital plant and animal genetic resources, must be suspended or eliminated.

At the national level:

1. Whenever four or fewer enterprises control 25% or more of sales in any commercial sector relevant to food and agriculture, in any geographic market, in any one of the three most recent years for which data are available:
    a. The corporate clique should be investigated; if a cartel is identified, it should be dismantled so that it does not collectively control more than 25% of the market and no single enterprise controls more than 10%;
    b. Appropriate government agencies should individually examine all intellectual property, inter-firm arrangements (e.g., joint ventures, strategic alliances) to eliminate restrictive business practices; and,
    c. If an illegal cartel is identified, the enforcement of all forms of intellectual property held by any member of the cartel that is relevant to the operations of the cartel should be suspended.
2. Enterprises should be required to make publicly available any information that is relevant for determining market share (e.g., business segment revenue) and defining terms of inter-firm arrangements such as strategic alliances and joint ventures.
3. Governments should strengthen or implement national competition policies that include strong anti-monopoly and -combines provisions that protect small food producers as well as consumers, as an effective mechanism to impede cartel formation.
4. Especially given the urgency of climate change, policymakers

should challenge the legality of an enterprise selling seeds whose viability and/or productivity is dependent on that same enterprise's agrochemicals.

At the international level:

-The UN Committee on World Food Security (CFS) should request the High-Level Panel of Experts (HLPE) to immediately undertake a study of the impact on food security of cartels and corporate concentration in food and agriculture with a view to recommendations for national, regional and global regulatory action.

-The UN Conference on Trade and Development (UNCTAD), in cooperation with other relevant multilateral agencies, should undertake a study of the capacity of national governments, regional intergovernmental associations, and the UN system to monitor and control industry cartels and corporate concentration and make recommendations for the establishment of appropriate regulatory measures and mechanisms.

-The CFS should convene a special conference on "Agriculture, Climate, and Innovation" in order to assess the capacity of the industrial food chain, the peasant food web, and alternative food systems to successfully innovate to ensure food security to address climate change.

II. The "Occupy Movement" – Getting Seeds out of Banks and into Farmers' Fields within and across Regions: By most accounts, germplasm exchange is stagnant even after nearly a decade of the International Seed Treaty (ITPGRFA), whose aim is the sustainable use of plant genetic resources. At the same time, the core budgets of international and national gene banks are being decreased. For example, according to Peter Bretting at USDA, the budget for the Plant Germplasm Preservation Research Unit (PGPRU) in Fort Collins, Colorado decreased by 6.8% from 2012 to 2013; the budget of the National Plant Germplasm System as a whole decreased by 10.6% over the same time period.[18]

In the case of the International Agricultural Research Center (CGIAR) gene banks, budget cutbacks have resulted in a shift in policy toward "full cost recovery," as well as some disturbing trends that undermine the CG centers' mandate to serve resource-poor farmers. During 2012, for example, ETC Group learned that the International Center for Agricultural Research in Dry Areas (ICARDA) based in Aleppo, Syria allowed private sector agents representing 3 major brewers in Mexico to gain exclusive access to barley germplasm held by ICARDA at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico; if the ICARDA germplasm proved to be suitable brewing material for industrial use, the $300,000 deal obligated ICARDA to withhold access from anyone in Mexico who requested it.[19] In other words, government-funded gene banks are giving private companies priority access to some farmer- donated gene bank material.

Actions with Policy Implications: In ETC Group's view, the urgency of climate change and the uncertainty of the future viability and accessibility of germplasm in gene bank collections (due to patent entanglements or contractual obligations to private sector "donors") provide compelling reasons to get farmers' varieties out of the major gene banks and (back) into the control of smallholder organizations. ETC Group has been working with partners to test procedures for requesting and receiving small sets of seed accessions from major national and international gene banks, which are obliged (if their governments are signatories to the International Seed Treaty) to provide upon request an unlimited number of seed samples to farmers, without cost, meeting all phytosanitary requirements and expenses and without conditionalities (i.e., no Material Transfer Agreement, tracking or reporting requirements). The tests are allowing partners to assess the speed and practicality of gene bank systems, as well as their own capacity to conduct small plot experiments and practice long-term storage. (Following initial tests, a report will be shared with all partners and with the gene banks involved.)

Stepped-up farmer-to-farmer seed exchange within regions and between regions (i.e., a "Great Seed Exchange") is the ultimate goal, whether the seeds come from national/international gene banks, community seed banks, or from farmers' fields. Farmers' organizations must strengthen their historic seed exchanges and plant breeding strategies (and be supported in their efforts). The key elements of an effective farmer-directed seed exchange include:

-Farmers' organizations must not only inspire but also actively direct and control the program and its resources; exchanges must move at the pace – and with a scope – determined by the organizations;

-Farmer-directed exchanges should involve both knowledge and planting material and the assumption must be that these exchanges can be encouraged to take place independently between farmers' organizations;

-If requested, as a matter of priority, national/international public programs and gene banks must comply with requests of farmers' organizations.

-National and international seed regulatory systems (including phytosanitary rules) must allow for and encourage farmer-led plant breeding and seed diversification.

-The mass distribution of seed to farmers for their experimentation, at best (i.e., if farmer-led), will "repatriate" farmers' varieties, encourage experimentation, stimulate diversification and protect against climate change. Repatriation does not necessarily mean returning the same seeds to the same communities. While the restoration of the "old" diversity can stimulate breeding options, conditions have changed:

-Temperatures are moving "uphill" 50 – 100 meters every year creating new opportunities but not alleviating the struggle with old soil and new water constraints.

-Pests and diseases are marching from the Equator to the Poles at about 3 km / year threatening conventional exchange systems that range only about 10 km. This means that, while exchanges between mountain regions such as the Andes, the Rockies and the Himalayas could prove immediately beneficial, even in the medium-term, mountain regions may need diversity from very different ecosystems. The Pampas, Punjab, Plains and Prairies may not – or may (emphasis is intentionally on the uncertainty) – have much to share.

Overcoming Policy Barriers to Inter-regional Seed Exchanges: Regulatory restrictions (e.g., phytosanitary rules) can complicate trans-national seed exchange. The ease of seed exchange across borders will depend upon both the species and the countries involved. The exchange could also depend to some extent on politics – who is sending seeds, who is receiving them, and for what purpose.

For example:

-An exchange between farmers' organizations in Colombia and Kenya may encounter opposition from either or both sending and receiving countries for phytosanitary reasons.

-A Kenyan farmers' organization that makes a request to the Colombian national gene bank (and vice versa) may not get a response, or the response could be very slow.

-An exchange between the national gene banks of Kenya and Colombia may be faster and require, in most cases, fewer phytosanitary considerations.

-An exchange between CIAT in Colombia and ILRI in Kenya (both international gene banks) may be fastest of all and have the fewest regulatory difficulties.

-Exchanges may be easier if the purpose is identified as "experimental" and the quantity is appropriately limited.

-Exchange may be the easiest of all if the seed multiplication is carried out by the receiving national or international gene bank and then afterward packaged for delivery to a farmers' organization.

Challenges to cross-border seed exchange need not be insurmountable as long as there is careful crop selection. In the final analysis, each farmers' organization will have to evaluate its national situation and decide what – if any – exchange is appropriate. Recognizing the unique threats posed by climate change and corporate monopoly, a "Great Seed Exchange" must reinvigorate localto-global knowledge and seed transfers, enhance enlarged, multi-generational community seed storage, and develop trusted mechanisms for sharing crop and climate information.

A Note on Community Seed Conservation: Until recently, ETC Group and others assumed that long-term seed security was possible only if the living collections in farmers' fields were backed up by at least two duplicate collections in temperature- and humidity-controlled gene banks far enough from one another to protect against calamitous events. For orthodox (most) seed, the operating assumption has been that the seeds must be stored at -18°C and below 5% humidity. Even then, the seeds have to be grown out, on average, every 10 years in order to ensure high germination levels. Because of the high costs involved, the need for good governance over decades and the importance of reliable electricity, the gene banks of choice have been the 11 international banks of the CGIAR. National gene banks, however, have always had the advantage of being closer to the farmers who gave them the seed initially and being better able to rejuvenate seed samples under their original conditions.

Scientists in the Netherlands and Spain have been conducting seed storage experiments that indicate that most crops can be stored on the farm or in the community without necessarily requiring electricity and refrigeration. Studies (completed and in process) by CGN, the Dutch national gene bank and Wageningen Agricultural University20 suggest that orthodox seed dried to a low – but not extreme – humidity level with almost no oxygen in laminated aluminum packages may survive much longer than under conventional gene bank conditions. The Dutch studies suggest that the seeds be stored under cold storage conditions, but the researchers also agree that temperature control may not be important for relatively long-term storage under ambient conditions in communities. At the same time, the gene bank in Madrid reports that seeds ultra-dried to below 3% humidity and hermetically sealed may maintain germination rates of 91% for at least 38 years and possibly much longer – without refrigeration.21 Ultra-dried orthodox seeds stored at 4°C had a 97.8% germination rate after 38 years and, again, could conceivably have acceptable germination rates after 100-200 years. Based on the Dutch and Spanish studies, the Kew Royal Botanic Gardens in the UK and Cenargen Embrapa in Brasilia, among others, are actively considering these technologies.22

While there is considerable scientific enthusiasm for the potential of using these technologies for not only community but also national storage, it would be a mistake for humanity to abandon back-up collections in conventional humidity/temperature controlled gene banks.23 However, the implications for farmers' seed sovereignty are substantial. At very little cost and with modest training, farmers and/or their communities can receive an inflow of diverse species and varieties without centralized control. Once packaged, the seeds can be stored on individual farms and be regenerated about once a generation, or every few decades. Natural or human-made calamities will not destroy the seeds unless the entire community is destroyed. Communities could conserve diversity locally and experiment with it gradually over several growing seasons. Whereas before, conservation and experimentation would have meant an intolerable and expensive burden, now it appears to be entirely manageable.

III. New Technologies & "Big Data:" In addition to legislated means of restricting access to agricultural biodiversity (e.g., restrictive licensing of proprietary seeds), there are also technical ways to hinder flexibility in the field. ETC Group has been tracking seed-sterilization technologies since the late 1990s, for example, and the threat of "Terminator technologies" persists,[24] despite a de facto moratorium on the technology agreed by 193 countries at the UN Convention on Biological Diversity. Synthetic Biology ("extreme genetic engineering") also requires careful monitoring for its impacts on agricultural biodiversity. Companies are now developing and/or bringing to market synthetic versions of natural plant compounds – including vanilla, stevia, coconut oil, cocoa butter, patchouli, rubber, vetiver and saffron. If these substances are able to compete with botanical products grown by tropical farmers, they could destabilize markets, destroy rural livelihoods and impact the sustainable use of biodiversity.

Using other new techniques known as "site specific mutagenesis," biotech companies are modifying plant genes without adding foreign DNA – a feat that enables them to avoid the transgenic or GE label and purposefully sidestep regulatory oversight. The USDA has quietly ruled, in at least two cases – Dow AgroSciences' "zinc-finger nuclease" technique and Cibus Genetics' "Rapid Trait Development System," which directs a cell's own DNA-repair system to make a specific desired change in a targeted gene – that the products of these techniques fall outside its regulatory authority.[25] The rulings are not without controversy and it remains to be seen if Canadian and European regulators are of the same mind. For the Gene Giants, the appeal of modifying plant genes with patented techniques while avoiding regulatory review and stigma of transgenics is spurring new R&D alliances.[26] Bayer CropScience, for instance, has trait development agreements with KeyGene and with Cibus Genetics. Cibus claims that its nontransgenic technique is not only "free of the market resistance and regulatory burden"[27] of GE seeds, but is also faster and less expensive than transgenic technology.

At the same time, Big Ag is making big investments in Big Data, including weather and climate data and on-farm analytics. Monsanto's purchase of Climate Corp. last November for $930 million revealed how seriously the company views its new "$20 billion market opportunity" for selling "data-driven products to help farmers boost production."[28] The implications for privacy and for commodity markets (and their potential to be manipulated), as well as for the price of seed and insurance, are as yet unclear.

Proposal for Action: In light of these rapid-fire technological developments, ETC Group has been advocating for increased capacity for technology assessment, both at the intergovernmental level and the level of civil society. We believe that civil society organizations (CSOs) can work together to (1) ensure that marginalized peoples have the early warning/early technology assessment they require, and (2) make UN-level assessment more effective through parallel monitoring processes at the regional, national and local levels. The highest priority is to organize regional "Technology

Observation Platforms" (TOPs) that can ensure the full and informed participation of marginalized peoples in technology issues important to them. The idea of TOPs has emerged from several CSO discussions held over the last three years in Africa, Asia and Latin America, following a global dialogue with social movement and CSO partners in Montpellier, France in 2008.[29] There has also been close cooperation with the World Forum on Science and Democracy, as part of the World Social Forum – in Belém (2009), Dakar (2011), Rio (2012) and Tunis (2013) – to advance a global dialogue on technology evaluation in general and on specific technologies, including agricultural genetics and synthetic biology.

As envisioned, each regional TOP would have at least four functions:

1) Respond to emergencies (the imminent introduction or loss of a technological option without consultation) on the basis of the Precautionary Principle.

2) Organize substantive and informed discussions – through citizens' juries, focus group discussions, roundtables, online surveys, etc. – that hear the views of all concerned parties and make it possible for marginalized peoples to publish their conclusions and recommend actions to address potential consequences of technologies.

3) Monitor medium and long-term science and technology developments of potential interest to its membership.

4) Communicate with other regional TOPs, governments, intergovernmental organizations, etc., as appropriate, to further regional understanding and/or global action.

An urgent need is for a regional TOP (or interregional TOPs) capable of monitoring technological developments that could (further) restrict or endanger the sustainable use of agricultural biodiversity. Targeted technology evaluation and monitoring could complement farmer-to-farmer seed exchanges by foreseeing threats, including technology-related threats from the Gene Giants who will quickly realize that the efforts of farmers' organizations to acquire gene bank accessions and conduct their own plant breeding undermine long-term corporate profit interests.

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Response to "What are the Key Challenges in Ownership of Seeds and how Best to Resolve?" : Turning the Tide: Confronting Monopoly Power in Plant Breeding by Jack Kloppenburg

TURNING THE TIDE: CONFRONTING MONOPOLY POWER IN PLANT BREEDING

Jack Kloppenburg[22]

There is a tide in the affairs of men.
Which, taken at the flood, leads on to fortune;

-William Shakespeare, *Julius Caesar*

The capitalization on such on such information by any one individual thus becomes a breach of faith in this principle of free exchange of information and material and seriously jeopardizes future continuation of such cooperative endeavor. -American Society of Agronomy, Special Resolution, 1956

Friends, please forgive the tardiness of this paper. I had an initial version almost done, but it seemed flat and not very useful and not even very honest. On Sunday morning, I started over with the intent to provide as clearly and succinctly as I can my view of where *sustainable* plant breeding (*not* necessarily *public* plant breeding) needs to be positioned if we are to work effectively for a just and sustainable food system. What follows is my own interpretation which I do not assume to be authoritative or even accurate. Nevertheless, this is frankly how I see things. I believe that we need to make some very substantial changes in our orientation if we want to win. It *is* a battle - against corporate power. And we have been losing.

At its annual meeting in 1956, the American Society of Agronomy took the unprecedented measure of censuring one of its members in a Special Resolution. Donald F. Jones was reprimanded for the "severe blow" he had struck to scientific cooperation by his patenting of the CMS/restorer system for producing hybrid corn. This event is now forgotten by most plant scientists who, when reminded of that ancient controversy, tend to regard it as an irrelevant anachronism rather than the normative sea-change that it was. Jones floated his patent at the very moment that the socio-political tide began to flood in favor of IPRs.

For the last 57 years that flood tide has indeed led on to fortune for a narrowing set of corporate entities which have used the monopoly power that IPRs confer to reinforce the monopoly power that they have increasingly enjoyed as a result of consolidation in the seed industry. The law been a consistent and powerful mechanism for commodification of the seed and for corporate empowerment in the United States, in Europe, and globally: UPOV (1961), PVPA (1970), *Chakrabarty* (1980), *Asgrow v.Winterboer*

(1995), J.E.M. *Ag Supply, Inc. V. Pioneer HiBred*, (2001), *Bowman v. Monsanto Co.*(2013), WTO/TRIPS,

[22] Professor, Dept. of Community and Environmental Sociology, University of Wisconsin-Madison

the International Treaty on Plant Genetic Resources for Agriculture. Absent either diligence or competence – perhaps both – the EPO and the USPTO now appear to be allowing patents on traits which are neither novel or nonobvious. Patents such as Syngenta's on a melon with "pleasant taste" elicit outrage from a few voices crying in the wilderness (viz., the inimitable Frank Morton), but remain largely unchallenged and mostly unrecognized. Concentration in the seed industry has now proceeded so far that intellectual property arrangements need no longer even be the chief means for disciplining the farmer. When competing companies and varieties are effectively absent, the dominant oligopolists are in a position to dictate to farmers the very conditions of access to seed via "shrinkwrap"-style bag tags.

Whatever their many differences, farmers of *all* types and in (almost) *all* places find themselves confronting Monsanto (and/or its corporate analogs) in similar fashion, with similar implications for their access to and use of seed. Plant breeders in public institutions, breeders in small seed companies, and farmer-breeders now find themselves in a position very similar to that of farmers. Increasingly, their access to genetic material, and even breeding methods, are constrained by the proliferation of intellectual property rights which are concentrated disproportionately among a narrow set of large and powerful firms. The debilitating effect of such limitations on these breeders' "freedom to operate" is accompanied by declining public funding and by institutional pressures to shape research in ways that complement – rather than compete with or provide alternatives to – the objectives and interests of the "Gene Giants." Rather than provide real alternatives to corporate cultivars (e.g., the glyphosate and 2-4D resistant varieties in Dow's new "Enlist" crop protection system), quite a few "public" land grant colleges of agriculture are aping corporate compliance policies and have joined their private allies in the "FYI" program which provides a tip line for farmers to inform on one another for alleged IPR infringements. The recent emasculation of the Justice Department's anti-trust initiative on the seed industry and the difficulty of advancing classical breeding support in the current Farm Bill further reflect the obstacles to effective transformation of public policy via political means.

Frustrated by apparent weakness of public policy initiatives in impeding the tidal flow of IPRs, some of us turned to the "private ordering" of contract law as a possible vehicle for a shift from continuous defensive actions to the creation of a positive, relatively autonomous space in which capital might be effectively prohibited – by its own rules – from trespassing. We formed the Open Source Seed Initiative (OSSI), hoping that we could developed an open source license that would preserve the right to use material for breeding and the right of farmers to save and replant seed by creating a "protected commons" populated by farmers and plant breeders whose materials would be freely available and widely exchanged but would be protected from appropriation by those who would monopolize them. Unfortunately, OSSI has concluded that such a license is not practicable.

Friends, we have been losing, and losing continuously and badly. Why have plant breeders of good will and sustainable aspirations (mostly public) not had more of an impact? I think there are a variety of related reasons. I think that some of the most important are:

1. *The critical importance of plant breeding is not understood by policy makers or citizens.* No one outside the plant breeding community itself knows what plant breeders do or why they do it or appreciate the critical positioning of seed is in agriculture. Few people at a farmers market know what a "cultivar" is or why the development of new varieties is a critical issue. Few people care.
2. *Public plant breeders have recognized but not been willing to highlight or seriously engage the core issue of corporate power.* Public plant breeders have always been aware of and concerned about the progressive erosion of support for their work and the ongoing process of their subordination to the priorities and operational parameters set by private industry. Their concerns, however, have been expressed mostly through episodic essays on "the future of public plant breeding" presented at various professional meetings (and ASTA conferences!). These documents are stuffed with euphemisms and inoffensive language. In the event they are published they appear in arcane journals and books and their often incisive take on the issues has remained internal to the plant breeding community.
3. *Public plant breeders have not defined a clear set of compelling rationales for supporting public breeding.* The same, tired old arguments have been used continuously for the last 57 years: "public breeding does what the private sector does not, and is especially suited to complex problems requiring sustained, long-term effort, economists have shown conclusively that returns to research are very high." How exciting.
4. *Public plant breeders have not been organized.* I know, this is hard. But except for a few episodic and regrettably abortive initiatives (e.g., Seeds and Breeds, OSSI), public plant breeders have not organized for collective action except within the established institutional confines of their professional associations.
5. *Public plant breeders have not reached out to potential allies beyond a relatively narrow set of organizations.* RAFI has long been concerned with the state of plant breeding and the public sector. The Organic Seed Alliance and the Clif Bar Foundation have emerged more recently. These are fine and effective organizations. Their support is necessary but not likely sufficient to effect the changes we need to see in public perception and public policy.

What is to be Done?

Given the foregoing analysis, what are some concrete actions that might be taken in order to strengthen the alternatives of sustainable plant breeding?

- *Explain and publicize the critical importance of plant breeding to policy makers, allied NGOs and citizens.* Make it clear to people what is at stake: the development of crop varieties capable of sustainably feeding a growing population in conditions of rapid climate change. Will those critical decisions be made by a narrow set of corporate executives responding to profit signals or by a broader set of decision makers representing a larger concept of public interest and equity.
- Persuade Michael Pollan to write a book about plant breeding and the seed industry (he was considering this) or at least write some articles.
- Persuade Bill Tracy to publish his marvelous, very clear and informative essay "What is plant breeding" in multiple versions and in multiple outlets.
- Do the same with authors such as W. Ronnie Coffman, Jim Coors, Charles Arntzen, Steve Jones, and R.G. Sears (all of whom have written on the future of public plant breeding).
- Recruit additional plant breeders – especially the new generation – to engage in thsi sort of discursive outreach.
- Establish the issue of corporate power as the point of departure for all advocacy on behalf support for public and/or sustainable plant breeding. This will be hard to swallow, but is essential. This should emphatically not be and need not be a blanket condemnation of the market or of private enterprise. The problem is the concentration of economic (and so cultural and scientific and political) power in too few entities. Monopoly power is the issue in seeds/breeding as it is in all other sectors. This is the core framing that will bring plant breeding advocacy into alignment with needed allies. Plant breeders and their allies should explore, understand, and comment on corporate malfeasance in the following vulnerable areas:
- Patenting of existing traits and obvious practices and operations
- Compliance activities that are ethically questionable (e.g., tip lies for farmers, outsourcing of enforcement)
- Difficulty of access to and use of germplasm (even under PVPA)
- Excessive prices for seed
- Problematic directions of corporate research - e.g., GMO/herbicide treadmill, opportunity costs, lack of locally adapted cultivars, etc.)
- *Develop a clear set of compelling rationales for supporting sustainable/public breeding.* Got to do more than say you complement private breeders and work on long-term projects. Also, I'm not even sure that arguing for "public breeding" is

the best way to go inasmuch as there are very cool private breeders (OSA, High Mowing, Wild Garden Seed, BrownSeed) and there are plenty of problematic examples of "public" breeding. Is "sustainable breeding" a way to go that gets *beyond* the maybe misleading public/private dichotomy? Anyway, a compelling set of rationales for *non-monopoly/non-Gene Giant* breeding needs to be developed. Surely the elements of that set will include

- Foremost and always DIVERSIFY THE PORTFOLIO-- the need in a context of profoundly uncertain and rapidly changing climatic conditions for DIVERSITY of cultivars to make and make sure we have RESILIENCE, generate OPTIONS in the face of uncertainty
- Corollary to (a) is that we cannot depend upon a narrow set of corporations to determine our agronomic future on the basis of market profitability signals, we need ALTERNATIVES to CORPORATE seed.
- The need for classical breeding (see Bill Tracy's paper) .
- The need for locally and regionally adapted varieties which the Gene Giants are clearly not producing.
- Participatory breeding - the need to incorporate the now underutilized labor power and creativity of farmers in the development of locally and regionally adapted cultivars
- FREE SEED! The need to have materials being developed that are freely and unambiguously (and maybe legally) available for further breeding.
- Who should do this? See point 4 below.
- *Get Organized.* Yes, it's hard. No, there is no one best way to do it. But someone has to do it. We already have RAFI (great organization, but breeding is only one of several issues it works on). We already have the OSA (great organization, focused on seeds/breeding, but also closely identified with organics). OSSI has now joined the alphabet portfolio (new organization and not stabilized yet). Do we need an organization that is focused on seeds/breeding with a big enough purview to encompass public breeders / private breeders / farmer breeders / farmers (and eaters?) under an umbrella that involves a clear oppositional (to corporate power) stance and an advocacy orientation?
- *Reach out to a broad set of potential allies.* Issues associated with seeds and breeding are not now a core concern of any of the principal tendencies within the overall sustainable food movement. We are not going to go anywhere without linking to one or more of those tendencies. "Public breeding" alone is just too narrow (and, for now, poorly understood outside of RAFI and OSA) to get much traction without additional social capital. Although the following

classification is a heuristic device, the following "tendencies" are associated with distinctive (though often overlapping) sets of NGOs/citizens'/advocacy organizations some or all of which ought to see sustainable seeds/breeding as a key part of what they are working for:

- The Good / Sustainable/ Local/ Organic Food Movement (e.g., Michael Pollan, Wendell Berry, Pure Food Campaign, Food and Water Watch, Organic Consumers Alliance, etc.)
- The Just / Fair Food and/or Food Sovereignty Movement (D-Town Farmers, Growing Power, Food First!, etc.)
- The seed saving / seed library movement (e.g., Seed Savers Exchange, Hudson Valley Seed Library, etc.)
- Farm organizations (National Family Farm Coalition, Farmers Union, etc.)
- The anti-GMO movement - this is tricky, GMOs are almost completely identified with the Gene Giants and criticism of corporate power in the seed sector almost inevitably associates the critic with an anti-GMO stance that may be uncomfortable for many scientific plant breeders (Millions Against Monsanto, GMO Free....., Cornucopia Institute, etc.).
- The European free seed movement (No Patents on Seeds, SWISSAID, Red de Semillas, Reseau Semences Paysannes, etc.)
- The Global South free seed movement (Via Campesina, GRAIN, ETC Group)
- Note that the call for support of the Tester

Amendment put out by RAFI/OSA attracted over 100 organizational expressions of support. The objective of outreach would be to strengthen and maintain and institutionalize such linkages.

Whither OSSI?

How might OSSI fit into this framework? Those of us associated with OSSI are, of course, disappointed that we could not develop a workable, legally defensible license.

Nevertheless, we plan to move ahead with a "free seed declaration" (the actual choice of an appropriate term – declaration, pledge, commitment – is still under discussion). The declaration will consist of a simple, very short, affirmatively phrased statement expressing a commitment to allowing unrestricted use of the seed and its derivative progeny lines. Notably, the "pledge" is not a "license" and is likely not legally binding (though OSSI is exploring ways to preserve this feature). This represents a shift in OSSI's strategy from "legal economy" to "moral economy."

The language of an OSSI declaration, sufficiently brief to allow printing on a seed packet, should be an effective tool for outreach and conscientization. Frank Morton, with his accustomed prescience has already pioneered such a procedure, offering his "Freedom Mix" lettuce seed in his 2013 Wild Garden Seed catalog under the following proviso:

"*It is freely offered here with the stipulation that anything derived from it must also remain freely available for others to use. No whole plants, seeds, or traits derived from this breeder's mix may be patented or protected from the use of others in any way. They may expressly be used by others for crop production, seed increase, and breeding purposes, though they may not be used in any way that restricts their use by others, now or in the future.*"

UW breeder Irwin Goldman plans to release carrot lines under the OSSI declaration which in draft form now reads:

This Open Source Seed Initiative pledge is intended to ensure your freedom to use the seed contained herein in any way you choose, and to make sure those freedoms are enjoyed by all subsequent users. These seeds are free in every sense of that word except that they and their derivatives cannot be legally protected by patents, licenses, or otherwise restricted in any way.

If you open the container that holds these seeds, you are agreeing that you may plant, eat, grow, cross, breed, share, save, transfer, sell, replant, or use them in any manner you wish. If you transfer these seeds or their derivatives, including crosses you have made with these seeds, they must also be accompanied by this document.

OSSI is now considering what additional roles it might play in the struggle for seed sovereignty. Actions under consideration include:

- Release of materials under the OSSI "free seed declaration"
- Development of a logo/trademark for OSSI declaration materials
- Compilation of corporate patenting of traits (with OSA)
- Compilation of breeder's codes of ethics
- Compilation of a portfolio of extant licensing arrangements attempting to preserve access for breeding
- Outreach to potential allies

In conclusion, I submit these comments as a set of propositions for debate and discussion, not as a plan.

Response to “*What are the Key Challenges in Ownership of Seeds and how Best to Resolve?*” : “Seed Privatization and the Path toward Equitable Exchange” by Kristina Hubbard

Seed Privatization and the Path Toward Equitable Exchange

Kristina Hubbard[23]

"The land-grant university system is being built on behalf of the people, who have invested in these public universities their hopes, their support, and their confidence."

— President Abraham Lincoln upon signing the Morrill Act, July 2, 1862

"The crops that we grow are the basis of our civilization. If anything belongs in the public domain, it is the crops we grow for food."

— Todd Leake, North Dakota grain grower, public testimony at a Department of Justice workshop in Ankeny, Iowa, March 12, 2010

"If we will not endure a king as a political power, we should not endure a king over the production, transportation, and sale of any of the necessaries of life."

— Sen. John Sherman, in proposing the Sherman Antitrust Act of 1890

Overview

Once managed as a public resource, seed is now one of the most privatized agricultural inputs today. Laws, policies, and practices governing intellectual property (IP) on plant genetics have fostered dramatic marketplace and cultural changes in a few short decades. The commercial seed marketplace has undergone tremendous structural changes, with ever more market power concentrating into the hands of fewer firms. IP rights have facilitated this extensive and rapid concentration. Beyond market domination at the retail sales level, farmers, plant breeders, and independent seed companies are dealing with the consequences of concentration at the more fundamental level of ownership, where IP owners determine whether germplasm is shared and how it is used. This paper provides a short history on what led to increased privatization in seed; the impacts of this privatization on breeders, farmers, and innovation; and recommendations for addressing root causes of the problem, including inappropriate IP tools, weak antitrust oversight, and the Bayh-Dole Act. This paper encourages much-needed policy change informed by a close examination of the trends identified herein, as well as new models for plant breeding and IP protection that decentralize ownership of seed.

A short history on the privatization of seed

A core function of the U.S. Department of Agriculture (USDA) when it was formed in 1862 was the collection and distribution of germplasm. Concerted efforts to introduce new plants to the U.S. began centuries before. For much of

[23] *Director of Advocacy, Organic Seed Alliance*

the 19th century, before USDA was established, the Patent Office fervently carried out these activities, mailing millions of seed packages to farmers across the nation.

By the end of the 19th century, a third of USDA's budget was allocated for germplasm collection and distribution. The department encouraged farmers to trial any crop that seemed economically important to U.S. agriculture, and continued the practice of distributing seed free of charge. And, thanks to the Morrill Act, states now had a place in the plant sciences through the newly established land grant university system. Land grants largely focused on collecting germplasm and conducting research in areas that were not profitable to burgeoning private ventures. Together, USDA and our land grant universities aimed to expand agriculture for the sake of prosperity and security – to further research, education, and innovation, and make advancements accessible to all.

USDA freely distributed seed to farmers not so much as a commodity but as an essential natural resource best managed in the hands of the people. The department understood that the nation's growing crop diversity was a product of farmers serving as the nation's first plant breeders. Their labor and land – and the knowledge base they built through experimenting, screening, and selecting – effectively adapted exotic plants to regional agricultural environments.

Land grant universities' regional breeding programs gained momentum, providing new plant varieties to farmers. These public programs advanced U.S. agriculture by increasing yields and developing a strong base of scientific knowledge. Private companies emerged and expanded, and soon organized to confront their most formidable competitor: the government. In 1924, after years of lobbying, the seed trade convinced Congress to shut down USDA's free seed distribution. Over the decades that followed, the number of seed companies grew.

The political climate was such that lawmakers were facing heightened pressure throughout the 20th century to create policies that protected investments in research and development. IP rights had been discussed for decades, and the first law to provide breeders some protection passed in the form of the Plant Patent Act of 1930. Importantly, the law only applied to asexual reproduction, such as grafting and cuttings, and excluded sexually reproducing plants as patentable subject matter.

In fact, Congress long argued that sexually reproducing plants should not be awarded utility patents under the U.S. Patent Act – "patents for invention" – for fear of curtailing innovation, threatening the free exchange of genetic resources, and increasing market concentration. A 1966 congressional committee report states that while its members "*acknowledge the valuable contribution of plant and seed breeders, it does not consider the patent system the proper vehicle for the protection of such subject matter*" (Report of the President's Commission, 1966).

But the seed trade and plant breeders were eventually successful in convincing Congress that more protection was warranted. This came in the form of a "patent-like" protection under the Plant Variety Protection Act (PVPA) of 1970. The law represented a compromise: Breeders had the exclusive right to propagate and market varieties for 20 years, but the law provided important exemptions. First, other plant breeders can use varieties protected by a PVP certificate for research, including plant breeding. Second, farmers can save seed from protected varieties to replant on their own farm. (Prior to 1994, this exemption also allowed farmers to sell saved seed.)

Although PVP protections are still widely used today, Congress' concerns regarding IP and plants have been realized, but not because of the PVPA. In 1980, the U.S. Supreme Court upheld the first patent on a living organism in *Diamond v. Chakrabarty*. The PTO had originally refused to award this patent, which involved a GE bacterium, before Chakrabarty appealed. In 1985, in *Ex parte Hibberd*, the Board of Patent Appeals and Interferences effectively extended the *Chakrabarty* decision by allowing a broad utility patent on plant matter (*Hibberd*, 1985). A 2001 Supreme Court decision later affirmed in *J.E.M. Ag Supply vs. Pioneer Hi-Bred International* that the scope of the Patent Act was not limited by the Plant Patent Act or the PVPA. Although utility patents awarded for seed and plants increased after the earlier 1980 and 1985 decisions, this Supreme Court ruling eliminated remaining uncertainties around utility patents on plants, opening the floodgates to further privatize our plant genetic heritage.

Patents and licensing agreements

Owners of utility patents have far-reaching control over access and use of their protected products. A single patent can cover a plant, seed, tissue cultures, future generations, crosses with other varieties, and the methods used to produce it. While the PVPA has exemptions for researchers and farmers, utility patents can be legally enforced to forbid access to protected material for purposes of research, including plant breeding and on-farm seed saving. Patents therefore remove valuable genetic material from the diverse pool of resources breeders rely on for improving agricultural crops. When access to breeders is provided, it often hinges on restrictive licensing agreements.

Patents are also commonly enforced to remove a farmer's right to save and replant seed, the very practice that helped establish much of the tremendous diversity of domesticated crops and varieties we have today. By being forced to repurchase seed each year, farmers not only shoulder higher annual input expenses, they lose the ability to adapt seed to regional climates, soils, and disease pressures.

Today, in many an industry, be it agriculture or software, the scope of licenses that communicate patent rights (or simply serve to transfer material and dictate the terms even in absence of a patent) has expanded beyond their traditional use. Many licenses now transfer IP without transferring many presumed rights of the user, upsetting the balance that public policy aims to achieve between IP owner rights and the public interest (Winston, 2006).

In agriculture, the ability of IP owners to restrict seed saving epitomizes this shift away from the public interest. With the proliferation of patenting and licensing, farmers began seeing licensing agreements on their seed bags ("bag tag" contracts) that communicate patent rights to growers. The aggressive enforcement of bag tags is most notable with agricultural biotechnology products – genetically engineered (GE) seed – though bag tags are increasingly found on non-GE seed bags and even vegetable seed packets.

Many growers of GE crops – specifically, soybeans and cotton – suffered a rude awakening beginning in the late 1990s when the Monsanto Company began spending millions of dollars on private investigators to go after farmers who were allegedly infringing its patents by saving seed. By 2005, the company had carried out thousands of investigations and filed approximately 100 lawsuits against its customers (Center for Food Safety, 2005). Many more farmers who were under investigation paid expensive settlements and signed gag orders to avoid legal action. Once Monsanto started down this path of using strong-arm tactics, rivals followed. DuPont started investigating seed saving among its farming customers in 2013 (Kaskey, 2012).

The expansion of IP rights facilitated increased concentration of financial and genetic resources. The enormous profits from licensing patented products led to dozens of acquisitions and mergers in a short timeframe. As a result, farmers and businesses now operate within a highly consolidated seed marketplace.

Concentration and its consequences

Rapid consolidation in the seed industry should have raised eyebrows at the U.S. Department of Justice but instead went unchecked. For example, the dominant firm, the Monsanto Company, achieved its No. 1 position in the seed industry in less than a decade by capturing the markets for corn, soybeans, cotton, and vegetables.

Concentration in the seed industry is well documented. Dr. Phil Howard of Michigan State University has followed agribusiness concentration through articles and information graphics, including trends in the global seed industry. Howard's most recent research reveals that, while corn, soybeans, and cotton are highly impacted by consolidation, the trend is growing in other crops, including vegetables, and that consolidation continues at a rapid rate. The top eight firms acquired more than 70 companies in the last five years alone (between 2008 and 2013). The Independent Professional Seed Association estimates the U.S. has lost more than 200 companies in the last two decades alone (Wilde, 2009).

Economists have established that an industry loses its competitive character when the concentration ratio of the top four firms reaches 40 percent or higher. In seed, we've clearly exceeded that benchmark. Three firms (Monsanto, DuPont, and Syngenta) collectively control more than half of the global seed market, up from a 22% share in 1996. By crop type it's even more telling, where four major biotechnology and chemical firms command 86% of the retail market for corn. The top two firms (Monsanto and DuPont) account for 66% of this market and 62% of the soybean retail market (Matson et al., 2012).

This level of concentration in corn and soybeans has meant less choice for farmers and skyrocketing prices, regardless of whether farmers choose to grow GE or conventional (non-GE) seed. Demand for non-GE soybeans surged in 2009 as prices of GE seed increased dramatically and the problem of herbicide-tolerant weeds worsened. Finding suitable alternatives proved difficult, if not impossible in some regions.

Patents are expensive, so it's no surprise that the top two industry leaders that have profited tremendously from IP rights on seed are also the top two owners of utility patents on plant varieties. Between 2004 and 2008, Monsanto and DuPont accounted for 60% of these applications (Pardey et al., 2013).

Yet, contrary to the claims of these firms and other IP owners, patents and restrictive licensing has not spurred innovation in crop improvement. In fact, the opposite appears true. For example, in plant biotechnology, USDA documented that as the corn, soybean, and cotton markets became more concentrated "private research intensity dropped or slowed" relative to what would have occurred without consolidation (Fernandez-Cornejo & Schimmelpfennig, 2004). That's why leading economists, including Dr. Neil Harl of Iowa State University, warn that firms become complacent and less likely to innovate when they can produce less and obtain a higher price for their input (Harl, 2000). Market protection in the form of antitrust oversight is needed to prevent undue concentration of economic power and to encourage innovation.

DOJ and USDA abdicate their role in confronting seed concentration

In 2010, the U.S. departments of Justice and Agriculture began to take a hard look at anticompetitive conduct in the seed industry. The agencies hosted five workshops across the country that year to discuss competition and regulatory issues. These workshops were historic. Never before had the two departments joined forces in an effort to examine antitrust issues in agriculture. And yet, despite well-attended public workshops (approximately 1,700 people attended the Colorado workshop) and more than 18,000 written comments, the agencies failed to take action in response to the compelling evidence provided.

The public comments represented a range of agricultural industries – from poultry to hogs to cattle – yet seed remained a prominent subject of public comments delivered at each workshop. Comments called on USDA to protect genetic diversity in seed, to keep germplasm public and accessible to our public land grant universities, and to address the abuse of patents as they are being applied to seed.

Even the assistant attorney general for the DOJ's Antitrust Division, Christine Varney, who has since left the DOJ, highlighted the problem of patents in her opening remarks: "You know, patents have in the past been used to maintain or extend monopolies, and that's illegal, and you can be sure, Secretary, that we are going to be looking very closely at any attempt to maintain or extend a monopoly through an abuse of patent laws" (DOJ and USDA, 2010).

Fourteen state attorneys general also contributed to the conversation:

In a concentrated industry, law enforcers must carefully analyze whether any holder of intellectual property is acting within the scope of its patent in imposing any restrictions on the use of the claimed invention. The complexity of the seed industry requires a thorough understanding of the industry, current antitrust jurisprudence, and intellectual property laws. State Attorneys General, the DOJ and USDA should explore the concerns which have been raised and consider whether there are bases for changes in policy and existing laws.

Three years earlier, in 2007, at least two state attorneys general initiated investigations into Monsanto's business practices. A federal investigation followed in 2009.

The federal investigation seemed to focus solely on competition among biotech trait developers – squabbles between the largest industry players, including complaints made by DuPont and Syngenta against Monsanto over biotech trait licensing agreements. According to public documents and media reports, the state investigations may have been broader, focusing not only on whether licensing agreements were unlawful but if Monsanto had used its dominance to illegally maintain a monopoly.

Still, the root causes of the lack of competition seemed to largely go ignored, including investigations into an "abuse of patent laws," as Ms. Varney stated. [6] The agencies should have broadened their investigation on a number of levels, including taking a hard look at the interface of IP laws and antitrust laws – a balance that, at least in seed, is clearly tipped toward the protection of patent rights at the expense of competition.

But any hope that state and federal agencies would expand their investigations was short-lived. Two years later, the DOJ issued a report outlining some complaints heard at the workshops (DOJ, 2012). But the agency's response ended there. The agency also closed its antitrust investigation into Monsanto because of "marketplace developments that occurred during the pendency of the investigation" (Khan, 2013). The developments included a new licensing deal between Monsanto and DuPont. State antitrust investigations also closed that year. Therefore, both state and federal regulators have failed the public in fully investigating how concentration, patent rights, and licensing practices facilitate unfair market advantage in the seed trade, inhibit innovation for the public good, impinge farmers' freedom to operate, and increase social costs and risks.

Patenting and licensing at our public universities

The practices of patenting and licensing have been more visible in the private seed trade, and therefore the consequences as well (i.e., market concentration, legal disputes, higher seed prices, and seed saving restrictions, to name a few). How patenting and licensing have impacted public plant breeding and other seed research at our land grant universities, on the other hand, is less understood and demands a serious examination.

Academic research in general has become more privatized over the past quarter century. More industry funding is directly supporting university research (Mowery et al., 2001). And, as explained below, universities increasingly use patents and licensing to disseminate research as opposed to placing it in the public domain. Bhaven N. Sampat (2006) has documented this shift. Universities were historically reluctant to patent and license their inventions for fear they might be seen as compromising their commitment to "open science" and their institutional mission to broadly disseminate knowledge. Throughout much of the 20th century, many universities avoided patenting altogether, while others took a hands-off approach by leaving patenting decisions and management up to the inventor and outside entities.

The 1970s saw a marked growth in university patenting. Sampat (2006) argues that this is likely because of the increase in "use-oriented" basic research in fields like molecular biology, as well as a decline in federal funding for university research. Several universities were already entering into "institutional patent agreements" that allowed them to retain the right to agency-funded patents. Patent policies differed by federal agency, something that frustrated universities, which increased pressure on Congress to create uniform patent policy across all federal agencies.

Uniform policy came in the form of the Bayh-Dole Act of 1980. Universities and businesses could now obtain the rights to any patents resulting from grants or contracts funded by any federal agency. Not only did Bayh-Dole make it easier for universities to patent and license their research, it largely eliminated the reluctance to do so.

Prior to Bayh-Dole, universities' fears that patenting and licensing practices would be frowned upon by the broader public likely provided a check on their ambition to widely patent academic research, especially for profit, and especially in cases where other channels of dissemination were sufficient (Sampat, 2006). Today, a practice that used to give universities pause is now proudly embraced and celebrated.

Although universities were patenting research before Bayh-Dole, the number of universities involved in patenting and licensing more than quadrupled between 1980 and 1990 (Sampat, 2006). The number of patents awarded to universities also climbed following its passage, from fewer than 300 a year to more than 3,000 (Sampat, 2010). Universities now earn almost $2 billion annually from licensing (Sampat, 2010).

These figures are now widely used to boast the success of Bayh-Dole, to claim the law was necessary for improving technology transfer of publicly funded research. But numbers demonstrating increased patenting and licensing of university research (and income generated) don't necessarily mean more outputs are being transferred, that the public good is being served, or that profits are coming back to research and development programs. In fact, evidence has emerged that challenge these supposed benefits, at least in the broad context of academic research. There remains a major gap in literature on how Bayh-Dole has impacted plant breeding and seed research specifically. Still, the following findings are instructive.

First, Bayh-Dole was passed on little, and some argue faulty, evidence that patenting and licensing were necessary for improving the commercialization and development activities at universities. These activities, and their potential impacts, weren't well understood when Bayh-Dole was passed in 1980 and they are still not well understood today. Therefore, the claims that BayhDole was necessary to enhance technology transfer – to improve commercialization and innovation – are unfounded (Sampat, 2006; Mowery et al., 2001). More importantly, the value of public research and the potential risks of passing BayhDole were neglected during the bill's hearings (Sampat, 2006).

Second, the arguments for Bayh-Dole dismiss other forms of research dissemination, including: consulting, publishing, public conferences, teaching, and hiring students. In fact, surveys show that most industries rank patents and licensing near the bottom of the list when asked how they learn from university research (Cohen et al., 2002). Publications, conferences, consulting, and informal exchanges ranked highest – channels that keep research in the public domain, benefiting future academic research as much as industry (Sampat, 2010).

And, third, some universities have strayed from the purpose of Bayh-Dole, where the transfer of technology for the public good may not be driving patenting and licensing decisions as much as their desire to generate income. Another survey of 62 research universities shows that licensing income is the most important criterion by which technology transfer offices measure their success (Thursby and Thursby, 2001). Notably, generating income from patenting and licensing was not an established purpose of Bayh-Dole at the time of its passage.

Although universities can demonstrate increased income on account of patenting and licensing, this income doesn't necessarily provide a funding stream for more academic research. The Brookings Institution concluded that, in any given year, the revenue funneled into university budgets from patents and licensing deals is not enough to cover the cost of running most technology transfer offices (Valdivia, 2013). Other studies similarly show that earning licensing income from academic research is often not lucrative (Sobolski et al., 2005).

As mentioned, a comprehensive analysis is lacking on how patenting and licensing impacts university plant breeding and other seed research specifically. However, examples of problematic practices have emerged. For example, the same licenses that restrict farmers from saving seed also restrict independent research. In 2009, 26 corn-insect specialists submitted anonymous comments to the Environmental Protection Agency (EPA) about licenses enforced by biotechnology firms, stating, "*as a result of restricted access, no truly independent research can be legally conducted on many critical questions regarding the technology*" (Editors, 2009). Specifically, scientists said the licenses were keeping them from researching the effectiveness and environmental impact of GE crops. Instead, university scientists have to seek permission, which is sometimes denied or comes with strings attached, such as whether the findings can be published.

The anonymity of these scientists showcases the fear that powerful IP rights create. This includes fear of enforcement and fear of losing industry support for university research. Industry funding of public research may not be something to criticize on its own, especially in light of dwindling public funds. But it's clear that industry funding and licensing agreements can come with strings attached that dictate the terms and direction of research. Crop research in general has narrowed, prioritizing commodities where the most profit can be made, leaving minor crops and smaller markets underserved. There is also a fear of the unknown, where university researchers say they can't easily know whether germplasm they're using is patented. Especially problematic is the increased trend in broad patents that include traits that also occur in nature and are selected for through classical breeding methods, such as "red" lettuce and "brilliant white" cauliflower (Hamilton, 2014).

The broader shift in U.S. policy toward stronger rights for IP owners has contributed as much, if not more, to increased patenting and licensing at universities as Bayh-Dole (Mowery et al., 2001). Court decisions that greatly expanded the definition of patentable subject matter were game changers, as discussed above with the cases of *Chakrabarty, Ex parte Hibberd,* and *J.E.M. Ag Supply*. Given these changes, the extent to which living organisms – from new plant varieties to the identification of useful genetic traits – are patented and licensed by research universities demands careful analysis. This is especially prudent (and urgent) given the mission of our land grant universities and the importance of plant breeding to our nation's food supply, agricultural economy, and germplasm conservation systems.

Utility patents on living organisms have only been challenged in a few cases. In 2013, the Supreme Court ruled on two relevant cases: (1) the patentability of human genes, and (2) the patent exhaustion doctrine as it relates to saving patented seed.

In the first case, at issue were breast cancer genes identified and sequenced by Myriad Genetics, a molecular diagnostic company. In *Association for Molecular Pathology v. Myriad Genetics* (2013), the Supreme Court unanimously held that "a naturally occurring DNA segment is a product of nature and not patent eligible merely because it has been isolated," invalidating Myriad's gene patents. (The decision reiterated, however, that the Court still views utility patents on plant varieties appropriate.)

Whether the Myriad ruling leaves a door open to further challenge how patents are applied to seed remains to be seen. Justice Elena Kagan's comments suggest it does. "Our holding today is limited – addressing the situation before us, rather than every one involving a self-replicating product," she wrote. "We recognize that such inventions are becoming ever more prevalent, complex and diverse."

The second case, *Bowman v. Monsanto,* reflected that complexity. In this case the Supreme Court ruled that "patent exhaustion does not permit a farmer to reproduce patented seed through planting and harvesting without the patent holder's permission" (*Bowman v. Monsanto*, 2013). Beyond trying to save money, this farmer was challenging the relatively new paradigm of allowing utility patents on living organisms. In 2011, the Organic Seed Growers and Trade Association sued Monsanto challenging some of its patents on GE seed. The court sided with Monsanto by dismissing the case.

Where do we go from here?

We must step up our response to the abuse of patents and licensing, and simultaneously work to decentralize our nation's plant breeding, seed production, and distribution systems. Because of the complexity of IP issues, especially as they pertain to seed, the role of numerous decision makers and stakeholders must be considered in the policy pathway moving forward. This pathway must clearly articulate which forms of IP protections are appropriate, especially those governing public research. Specifically, as a community, we should consider the following ideas and recommendations.

Utility patents on plant genetics must be confronted

The law needs to change. Utility patents are the wrong tool for protecting new cultivars and other germplasm. Their application, especially coupled with restrictive licensing agreements, is unethical, resulting in grave economic and social consequences. Utility patents should not be awarded for seed and plants, and for any living organism for that matter. Though not a silver bullet to the multifarious challenges discussed in this paper, confronting the abuse of patents and licensing agreements is paramount to building broad support for the models of plant breeding and IP we must foster. This education, research, and organizing must include our public universities.

Furthermore, we should consider creating tools that assist plant breeders in accessing information about existing patents, including new patents that may impact their work as well as patents that are ending and freeing up material. Many breeders relay that they often don't know if and when they may be infringing a patent, and it's difficult to find out. This reality creates undue fears in our public plant breeding community, and serves as another barrier to innovation. We should also create a system that allows breeders to report examples of patents that are especially egregious and should be challenged in court, such as patents on naturally occurring traits.

The DOJ and USDA must further investigate seed concentration

Chemical and biotechnology firms have merged with or acquired a significant number of competitors, and though some have drawn antitrust scrutiny, no meaningful action has been taken to further investigate the impacts of this level of consolidation. Independent seed companies say the licensing agreements they sign with larger firms unreasonably restrain competition. University breeders say these agreements keep them from conducting important research on protected products. The public must be protected from predatory practices that ultimately hinder innovation and independent research.

The balance of power is currently tipped toward IP owner rights and away from the public interest. This imbalance must be seriously considered as part of a new investigation that includes a hard look at the interface of IP laws and antitrust laws. For starters, restrictions on research and germplasm exchange must be removed from licensing agreements, since independent research relies on access to protected products for purposes of innovation and information sharing.

For all proposed and pending acquisitions and mergers that could result in further concentration of the seed industry, the DOJ and USDA should establish a public process that assesses how the merger will impact the structure of agriculture. This assessment should be made public with ample opportunity for public comment prior to any governmental action on the merger.

Finally, antitrust law must be enforced when there is evidence of anticompetitive conduct. If the DOJ determines that anticompetitive conduct exists as a result of concentration in the seed industry or an abuse of patent and licensing rights, it should use all remedies at its disposal through the Sherman Antitrust Act and Clayton Antitrust Act to eliminate these practices. Breeders deserve to operate freely, without fear of infringing patent rights or conducting research that could reflect poorly on industry. And farmers deserve an open and fair marketplace that encourages innovation and provides a variety of seed options at competitive prices.

The impacts of Bayh-Dole on public plant breeding programs must be examined

The Bayh-Dole Act must be evaluated in the context of publicly funded plant breeding and other seed research. These findings should inform changes to the law, as well as changes to IP policies at universities and federal agencies administering research grants.

To what extent are university patents and licenses reducing access to germplasm and contributing to the "anti-commons" approach to plant genetic resource management? What criteria are technology transfer offices using to decide if and when to patent and license new cultivars and other germplasm? And at what cost to the public?

In the words of Bill Tracy of the University of Wisconsin, how do we encourage technology transfer programs that "have as their mission democratizing the seed sector rather than Balkanizing it?" There are likely opportunities to immediately address some of the constraints and frustrations that breeders have with their technology transfer offices, but it will take a deliberate effort. For starters, we should collect evidence of the problem as well as good, working examples, and then educate universities on best models and approaches to ensure shared value and future innovation, ensure royalties go to breeding programs, and ensure products remain in the public domain and serve the public good.

Finally, we should revisit the appropriate role of federal agencies in monitoring the patenting of public research, especially when broad dissemination is in the best interest of the public. Before Bayh-Dole, patenting and licensing policies varied between federal agencies given their differing missions and research and development programs. Plant breeding is a field of research that relies on the free exchange of germplasm and knowledge to succeed as a discipline and serve the public good. Therefore, agencies administering plant breeding grants should implement clauses in these contracts to ensure publicly funded research remains in the public domain.

Promote appropriate IP models for plant breeding

IP models that adhere to the principles of fairness, diversity, and shared benefits must be created and fervently promoted. Models will differ by breeding program and goals, and maybe by crop type. One example is the Open Source Seed Initiative (OSSI), described in Jack Kloppenburg's paper. Jack leads

OSSI's effort to "preserve the right to use material for breeding and the right of farmers to save and replant seed by creating a 'protected commons' populated by farmers and plant breeders whose materials would be freely available and widely exchanged but would be protected from appropriation by those who would monopolize them."

Our team at Organic Seed Alliance (OSA) has been exploring appropriate IP models in partnership with OSSI and other seed professionals to determine how best to protect new cultivars developed through our participatory plant breeding program while recouping a return for our program and farmer and university partners. We believe it is possible to encourage innovation and receive fair returns on investments without giving away our genetic heritage and future. We are poised to release two new cultivars in 2015 under licensing agreements that adhere to the spirit of OSSI and serve as example language for other breeding programs.

In 2011, OSA published the following principles to guide actions that foster organic seed systems, including the development of IP models (Dillon and Hubbard, 2011):

-Seed is a limited natural resource that must be managed in a manner that enhances its long-term viability and integrity.

-The equitable exchange of plant genetics enhances innovation and curtails the negative impacts of concentrated ownership and power in decision-making.

-The maintenance and improvement of genetic and biological diversity are essential for the success of sustainable food systems and greater global food supply.

-Farmers have inherent rights as agricultural stewards, including the ability to save, own, and sell seed, and are key partners in seed innovation.

-Public research should serve the public good and remain in the public domain.

With the help of a working group, we further identified key purposes of appropriate benefit sharing IP models, which included the need to:

- Ensure open access to plant genetics to preserve and expand this invaluable resource.
- Improve availability, choice, and quality of cultivars, especially cultivars appropriate for organic systems.
- Support the viability of independent seed companies and individual plant breeders.
- Help overcome resource constraints and enable smaller entities to compete.
- Foster investments that further innovation in plant breeding, including fair compensation for plant breeding contributions.
- Meet the needs of participatory plant breeding projects.
- Encourage information sharing and coordination.
- Reverse problematic trends resulting from the patenting of plant genetics, including barriers to accessing genetics due to outright denial, cost, onerous

licensing contracts, and fear of unintentional patent infringement.

We also concluded that appropriate IP models should have procedures to:

- Provide democratic management and an organized structure that encourages participation.
- Have a plan for dispute resolution.
- Acknowledge international context.
- Monitor progress and identify measurements of success.

A shared vision

Going back to the founding missions of our land grant universities and USDA, we need a significant shift in policy and mindset that recognizes seed as a public resource. Do we have to return to a time when most farmers saved seed and a third of USDA's budget went to the collection and distribution of seed? No, but we do need to recognize that seed demands careful management, and that it is best managed in the hands of many, not in the hands of few.

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Keynote Paper # 5: “Defining Value, Purpose and Role to Redesign Plant Breeding Institutions?”

Author: Michael Mazourek

MICHAEL MAZOUREK is the Calvin Noyes Keeney Professor of Plant Breeding in the Department of Plant Breeding and Genetics at Cornell University. His work focuses on the improvement of peppers, peas and cucurbits (squash, melon, pumpkin, watermelon and cucumber) for growers by increasing yield and production traits, consumers through enhancing flavor and convenience characteristics and the environment through pest and disease resistance that allow reduced pesticide usage. In addition to developing new cultivars with these traits, he trains students in plant genetics and plant breeding and shares these techniques with farmers interested in on-farm participatory breeding. These new seeds are created through traditional cross-pollination techniques and aided by new approaches in genomics that allow insight into the underlying science while still being compatible with certified organic seed. Mazourek received his Ph.D. from Cornell University in 2008.

Defining Value, Purpose and Role to Redesign Plant Breeding Institutions

Michael Mazourek[24]

I am writing on the topic of redesigning plant breeding from the perspective of a vegetable breeder that is in the final stages of establishing his own program. We have prioritized production traits geared to the grower and neighboring ecology, combined with consumer driven traits such as flavor and convenience. This is part of what makes us unique. Another of our unusual approaches is that we maintain an emphasis on breeding itself and demand that to be the driver of scientific inquiry. The personal tone of this paper comes from my own struggle of how to redesign the plant breeding program of my predecessors, Henry Munger and Molly Jahn, to keep it true to its legacy but also innovate and adapt it as they did during their tenure. For the purpose of this discussion, I outline the principles, resources and needs that I wrestled with in forming my approach and conclude with a potential opportunity to create a new institution of plant breeding.

The Problem

Starting fresh on a new design is a challenging proposition due to the inherent inertia to change, the preconceptions of existing solutions that limit our thoughts, and discriminating real versus imagined constraints. In the act of plant breeding itself, we are perpetually selecting plants that fit a certain set of criteria, many of which may be arbitrary, present for the sake of convention or to fit a system that has been designed around using crops that fit a certain specification. Thinking outside the proverbial box is a literal challenge in vegetables, where standard cardboard produce box dimensions can dictate produce size. Also, the discipline of plant breeding has evolved with certain sets of approaches and customs. With all traditions there is a core rationale of why something came to exist and the values they support, so to think freely about how to make change, and do so productively, these must be defined. The first step is therefore to define the system of plant breeding and the ideals and goals it is to support. Secondly, the existing constraints and structures and institutions should be considered. With this in mind, we can start to propose ways to rethink how this can best be done.

Plant breeding is the act of changing or modifying plant germplasm through selection. There are a great many other allied disciplines, approaches, tools, resources, etc that are valued partners in the process of plant breeding that should be thoroughly appreciated for the

[1]Michael Mazourek. Dept of Plant Breeding and Genetics, Ithaca, NY 14853
mm284@cornell.edu

insight and dimension they add to the process and reciprocally, we should strive to provide them value from plant breeding. They are however, partners in plant breeding, and these associated activities are not to be confused with the breeding of plants itself. The goals of this process are the seeds or propagules that will serve a practical or whimsical purpose.

Principles

There must be seeds that are a public good and there should be unrestricted access to the traits found in nature. These public seeds must be readily available for the production of food and other plant derived goods and functions (aesthetic, energy, fiber, etc). Seed that is believed to be an important repository of traits or combinations of traits must be preserved for posterity in a way that makes it accessible in the future. Seeds that have present value must be discoverable and made available through fair means. PVPs have historically served these needs fairly while still motivating investment in seed development; PVP protected material could not be propagated directly for commercial purposes or used as a hybrid parent, but further breeding was permitted which could utilize seed that was publicly archived as a condition of the PVP. Other initiatives that seek to join this landscape with new mechanisms only complicate and confuse the core principles. We have traditionally relied on a community approach that accumulates incremental gains.

There must be balanced input as to breeding priorities. Stakeholder input is incredibly important and often clearly represents the major, current concerns; these certainly should not be neglected. Other perspectives, including those of the plant breeders themselves, are of great value as well. These perspectives can advocate for underserved, smaller groups and forecast future needs. The development of solutions to resolved problems is challenging to support from stakeholders until after alternatives are required. Serendipitous discovery and creative innovation are difficult to mandate. Freedom and intuition are essential valued approaches in plant breeding as well as democratic mandates.

A new generation of plant breeders must be trained. The shift to molecular approaches in the 1980's left a void in the training of field based breeders. These new students need a breadth of experience. In addition to classical field based plant breeding, they need to be effective writers and speakers to not only advocate for their own funding, but also communicate the value of their discipline to the public. They need experience to collaborate effectively with other scientists and growers and interface with consumers.

Institutions

Land grant universities are a unique type of non- profit organization. They offer great opportunity to plant breeders in the form of tenure that provides them with a virtually guaranteed salary to pursue their discipline largely as they wish. The historical investment by state and federal funds provided for the vintage equipment many of us still use in our programs. Universities are often a stable institution to maintain knowledge and germplasm and provide a resource for the long- term ability to preserve this information in libraries and the archives of seed that persist without the risk of loss to the reorganization, economic viability, and market forces that affect private sector endeavors. Universities have reputation and community to make them a great attractor and provide the forum that attracts visitors and collaborators and people that want to think in new ways about seed along with a myriad of topics.

Seed companies can be agile with practical, timely investment in strategic areas from sources that are separate from the long delay and low odds of grant applications. They have sink-or- swim interest and drive to provide practical innovation that serves the market. They have a financial advantage when recruiting the best talent and are able to focus the energies of these hires on making progress without the distractions of the other responsibilities. For some, they have been able to develop resources that exceed those that are available to their university peers.

Participatory plant breeding has become a visible alternative to these institutions. By engaging growers directly in the breeding of their seed, the system of developing and maintaining seed is decentralized and customized. Two obstacles limit the spread of this approach. Growers often lack the time to dedicate a separate effort to seed production during an already busy season despite the benefits to be gleaned from adapted, in-house seeds. Raising a crop to mature seed can result in disease pressure issues due to the time of season or simply the additional time in the field. Beyond the tangible benefit of new seed, the process of breeding provides new insight to the farmer's land and seed and traits available to them. The exercise itself is invaluable to reconnecting to the history and intrinsic nature of their crop.

Within the System

My solution to how to design a plant breeding program at a land grant university focuses on adapting to my environment. The guiding principle was to engage ourselves in ways that are only accessible at a university, our specific university. Why this project, why here? I was attracted to a faculty position because it was the best opportunity for me to tackle issues I felt imperative. To make the most of this opportunity, we need to take advantage of all the institution has to offer. We are perpetually concerned with multipliers. We can't justify focusing all this potential on just a small group while neglecting greater needs. We need to invest in something where the impact will snowball. The question is how to work on these greater questions through the needs of our local region.

Student training is a natural component of what we do and has become how we staff our program; post-docs, graduate students, and especially undergraduates form a chain of mentorship held together by one full time and one part time technician. This provides an experiential learning opportunity that exposes students to all aspects of the plant breeding process. This is part of the new reality of funding plant breeding at a university; gone are the days of hard money staff. While

students are a high turnover workforce, they are one of the key areas to get the greatest return on investments: the breeding advance, training, and the impact of their future achievements all in one.
We study the science behind our breeding and genetics. Hypothesis based research is a critical aspect of the value of university plant breeding.

While it is common to design experiments that utilize aspects of plant breeding to identify novel parents, establish populations and score phenotypes for genomic analysis, and those that have the potential to yield results that could be utilized for plant breeding, we insist on turning the process around. We prioritize the breeding of plants. New sequencing technology allows us to do our science on these populations and follow the breeding process rather than repurpose our breeding program to the study of genetics

We engage in participatory breeding in a narrow sense. Although, we share our knowledge and approach broadly through on-farm plant breeding workshops, we approach it as we do contract breeding with companies. We work together to develop goals and evaluation protocols in the target environment. The pollinations and selections are performed at one of our university sites to best advance the process. We review progress cooperatively and discuss modifications to the approach. Seed becomes available through seed company distributors and we hold an authentic stock in case the need arises to replenish from the source. As there is interest, we publish.

We tell our story beyond our peers and growers. We engage as broadly with the public as possible. Otherwise, they are not only unaware of the importance of our work, they are unaware that plant breeding even exists at all. The growers we most directly serve are a minority, a 1% of the population. Despite the importance of this partnership, we are limited in how much we can serve this relationship by not expanding our relevance to be more broadly inclusive.

A New Institution
The combined activities of universities and companies can serve plant breeding reasonably well, but a need and opportunity exists for a third type of institution: a purely plant breeding institution. We have seen the value of this potential already as non-profit institutions have become more prominent and both undertake plant breeding as well as work with growers on participatory projects. Universities take on a great many responsibilities and functions which disperses their attention over many fields. One such distraction is the potential for ownership of seed, which complicates, entangles and restricts aspects of plant breeding. A non-profit also is limited in the types of goals it can undertake.

A organization focused on plant breeding has the potential to fill the void if it were started with sufficient momentum. This organization would naturally partner with both universities and seed companies in education and research. This is the ultimate solution to redesigning plant breeding, to be independent with a singular focus, and energies concentrated without internal distraction. At the same time, it could benefit from the academic environment with students in training at a university and company resources focused on market directed seed development and excellent quality control resources and infrastructure.

Response to *"What Kind of Partnerships / Models are Working and How Best to Accelerate their Adoption"*: The Perspective of a Breeder from a Non-Governmental Organization by Walter Goldstein

The Perspective of a Breeder from a Non-Governmental Organization (NGO)

Walter Goldstein[25]

There is a place for public investment in breeding to maintain a diverse, healthy agriculture. As royalties are based on sales, they cannot always remunerate the costs of developing diverse crops for less lucrative markets.

At the same time as public plant breeding is endangered at Land Grant Universities, NGO's are driving new interest in public breeding. New cooperative relationships are being built between NGO's and Universities. NGO's generate public interest and relevancy for breeding and engage underserved constituents. University scientists can backstop them with research and training. NGO's bring in new ideas, articulate needs, build expertise, and run breeding programs that produce cultivars that no one else will produce. New people take up breeding. Research and development work is done that helps seed companies that cannot afford to breed and also helps start new companies.

I will show you some examples of NGO activity, what we are learning, discuss the importance of revitalizing the art of breeding and some new ideas about breeding and funding.

For Northern Plains Sustainable Agriculture's (NPSAS's) Plant Breeders Club (Anon., 2014a), demonstration plots either on farms or at the North Dakota State University Carrington Research Center are a first step drawing farmers to evaluate crops (Kutka, 2014). At present these plots include ancient grains, cowpeas or vetch and radishes for soil improvement. This exposure and interest can lead eventually to adoption of new crops and small-scale breeding programs by individuals. Examples of present breeding capacity include David Podoll with corn and melons, Dwight Duke breeding potatoes, Emily Steigelmeier breeding radishes for soil improvement, and Frank Kutka breeding corn. NPSAS also collaborates with the "Youth Squash Breeding Project" carried out by The United Tribes Technical College (UTTC) in Bismark, North Dakota. Colette Wolf at the UTTC has also recently received a grant from USDA-NIFAAFRI for improving traditional corn varieties.

That project is being done together with NPSAS and three tribal community colleges in North Dakota and Montana.

Breeders such as Ted Skenandore at the NGO

Tsyunhehkwa in Oneida, Wisconsin have made great progress at restoring the viability of native corn simply by using mass selection over decades. That corn has become a

[25] Executive Director, Mandaamin Institute, Inc.

staple for the Oneida community and represents a healthy dietary development, made into very tasty products. This work has also engendered a sense of self-belief and value, and has made an improved version of the corn available.

In 1988 I was approached by a group of farmers in Wisconsin to improve the nutritional value of corn in and have worked on that first at Michael Fields Agricultural Institute and then at the Mandaamin Institute. I worked together with Iowa farmer with farmer Don Adams to mass select a population called Nokomis for several cycles. Later, with help from USDA-ARS we bred adapted, high quality inbreds out of that populations. Iowa farmer Dan Specht was also a research partner for over a decade. I supplied him with two high quality populations, and Linda Pollak, USDA-ARS supplied him with a third. He bred a productive polenta grade corn variety by the time of his death last summer, and with some help from Bill Tracy and other sources also produced an interesting sweet corn variety called Blue-Eyed Plantinum Blond.

The Mandaamin Institute, Inc. is an example of an NGO with a breeding program. We are breeding field corn using a standard inbreeding program with systematic yield testing of hybrids. We breed for adaptation to organic conditions, the ability to exclude GMO pollen (gametophytic incompatibility), enhanced nutritional value, and ability to obtain N with the help of microorganisms (Goldstein et al., 2013). Our mostly soft-kernelled corn is high in protein, and research with Iowa State University (Charles Hurburgh) and USDA-ARS (Abdullah Jaradat) has shown our corn is high in the essential amino acids lysine, methionine, cysteine, and tryptophan (Jaradat and Goldstein, 2013). Research at the University of Nebraska (David Holding) suggests that we are shifting the kind of proteins that are stored in the grain away from the nutritionally less valuable α zeins while increasing the more valuable β zeins, δ zeins, and non-zeins. Combining quality and yield is a challenge that takes investment and sustained effort. There is a need for public funding because private companies are often reluctant to make risky investments to develop new, less defined cultivars. They often want finished, trustworthy cultivars that are competitive and profitable in already existing markets.

We work in conjunction with local farmers to do breeding on their farms, in the context of a team project that includes universities (Margaret Smith, Cornell; Rich Pratt, New Mexico State, Charlie Hurburgh, Iowa State), USDA cooperators (Paul Scott and Jode Edwards), and a ex-industry consultant (Kevin Montgomery) with funding from NIFA-OREI. Participation in the team has provided opportunities for learning from each other, and a common organic winter nursery at the University of Puerto Rico.

At Mandaamin we are in process of trying to commercialize our first hybrids with help from Wisconsin farmer John Pounder and with pull through from organic food and feed companies. We also have started a research network for open pollinated corn with farmers John Pounder in Wisconsin, Merle Simrell in Missouri, and James Showalter in Virginia. They also learn how to mass select, produce seed, and to sell and distribute it with a royalty for sales eventually coming back to Mandaamin.

Valuing and Growing the Art of Breeding:

Part of the benefit of working with NGO's and farmers is that it can reinforce the human art of breeding. There is a tendency at Universities, reinforced by genomic funding, for curriculae to be focused on the molecular level ignoring whole plant performance. Breeders at large companies or in large university programs may not take the time to observe whole plant response anymore so evaluation becomes mechanized or even robotized into phenomic exercises carried out in artificial environments with experiments based on numerous assumptions.

But small breeding programs cannot afford this kind of research; the major resources are often the breeder. So, in contrast, as NGO/Farmer trainings are getting stronger we are putting in time with the plants in their natural settings and using selection skills to create 'out of the box' type cultivars that fill niches.

The art of breeding, the human/plant interaction may not be regarded as hard science but it is critical for financially efficient and effective breeding. It really has to do with building individual breeder capacity to assess, select, and decide, and take right measures and actions. To be effective the breeder needs to learn how to read the plant and represent its potential. I mean that in the sense of the capacities developed and demonstrated by Luther Burbank who took 'greater pains to understand the species he worked with' (Whitson et al., 1914) or Barbara McClintock (Keller, 1983) who developed 'a sense for the organism'. This implies time taken for active observation best backstopped by relevant data to avoid errors in judgment. At its highest level this entails years of exercising quiet, artistic observational skills, a full use of the human instrument for learning with the senses, an active imagination and development of correct intuitions based on constant feedback from numerical data. It presupposes taking time actively looking at the plants and evaluating them as they go through their development in order to know their strengths and weaknesses. A breeding program can be a continuous feedback and learning process for breeders, making it especially rewarding. A holistic approach is important as the breeder is a representative of what the plant can become and therefore has the responsibility that it is a balanced and enhanced whole that will evolve the species into the future in a beneficial way.

As a corn breeder, I have learned a lot from different University or USDA professors that I have spoken with, but have also learned a lot from practitioners and perhaps the most from professional corn breeders. Providing in the field training to develop the breeders eye and sense is critical. Building new educational partnerships to encourage selection and practice skills might well be cooperative between universities, NGO's, and professional breeders.

New Models for Thinking about Breeding: As we go into the future it may be important to expand the relevant model for investigation beyond performance of genotypes across environments. A new major model and theme might be:

Optimizing Breeder x Plant (Team) interactions in the context of fluctuating Environments.

Breeders: Reinstating and reintegrating the human element into breeding means being aware of our own role in the process. The breeder represents societal values of what the crop has to become. With that and beyond that, breeders differ, and what they produce reflects their attitudes and knowledge, insight, approach and goals. The footprint of the breeder is often apparent in their cultivars.

The plant team: Results of genomic research, epigenetic regulation, and the predominance of transposons in plant genomes reinforces my opinion that as breeders we are dealing with dynamic, self - regulating, and patterning plant organisms rather than gadgets. Their responses to selection are often not predictable. It is also becoming increasingly clear that associated microbes, including endophytes are providing essential services to the plant. These include the production of phytohormones, the accumulation of minerals and Nitrogen, and the ability to tolerate stresses. These services are playing a largely unexamined role for we who are in our profession of improving crops. Selection coevolves the species we work with and their microbial partners and changes the composition of the team and their roles. Certainly this is becoming relevant at the Mandaamin Institute as we select corn that responds to inoculation with bacteria to help the plant thrive and produce more protein. Hopefully new tools for molecular fingerprinting coupled with exercising breeder skills in the field may help us to eventually recognize, understand, and work with these plant 'teams'.

Environments: we need to think more about target environments such as breeding for success on both organic and conventional soils and dealing with multiple, and non-dependable environmental stresses in the face of climate change. Climatic effects associated with sites no longer seem to be as fixed as they were in the past.

Funding more cooperative and relevant, less competitive research?

The NPSAS staff has been very resourceful at obtaining grants from programs interested in their breeding activities. However, in general, funding opportunities for operational breeding programs are very limited for both NGO's and Universities and we need more funding to accelerate the work. These programs are long-term investments that improve over time, serve the farming community and the public, and need long-term support. If we wish to unite behind establishing a Breeding Institute such as what Michael Mazourek mentioned in his presentation in this conference, it is important and fair that it be regionalized in something like the SARE model (Anon. 2014b) and include long-term funding to multiple organizations and models, involving not only LGU's and seed companies but also NGO's, farmer breeders, etc. To a certain extent this might be facilitated by joint NGO/University partnerships for research in regionally significant crops. Such joint activities go into the level of starting new businesses. In practice, SBIR grants by startup seed companies probably need to involve universities if they are to be funded.

Other models for funding: I would like to refer you to some European models to expand our thinking on different models of how to finance plant breeding largely by small private breeders who are engaged in cooperative activities.

Public but non-governmental funding: The Foundation for Future Farming considers varieties to be a cultural asset so society as a whole is responsible for fostering it (Willing, 2007). The Foundation is part of the GLS Bochum Bank and has a fund to support organic breeding projects (Anon, 2014) in German speaking countries. In 2007 they disbursed 600,000 Euro's each year to 26 different breeding programs (Willing, 2007).

The fund is supported by consumers, philanthropists, retailers, processors, farmers, bakers, and others. It supports the breeding of cereals, vegetables, and fruit, but varieties remain open source (Anon., 2014c). Similar funding for breeding of organic crops, especially for programs associated with Bingenheimer Saatgut company, are available through donations and voluntary fees obtained by the Kultursaat Foundation (Anon., 2014d).

Combining Conventional and Organic

Breeding. To make breeding cost effective for organic farmers there are at least two European cereal breeding programs that do most of their breeding under conventional management but include selection under both conventional and organic production systems; (Birschitzky, 2007; Goldstein et al., 2013).

Clustering Farmer Breeders with companies: In Holland farmer potato breeders (J.P. van Loon, 2007) breed potatoes as a part time job. They are clustered around companies, receive clones derived from crosses from those companies, and select them for a four year period. The best of these clones are returned to the companies and further tested and developed. Should the potatoes find commercial use the farmers receive part of the royalty.

Creating Value Chains: In Switzerland the company Cereal Breeding Peter Kunz breeds diverse organic cereals (Osman, 2007). Kunz worked out an arrangement with the second largest food chain in the country (COOP) so that bread baked from their cereals is trademarked as 'Sativa Bread'. Kunz maintains quality control and interactions with COOP bakers and the COOP supports his breeding program. The millers in Switzerland also pay a fee for milling Kunz's cereals (Goldstein and Zschunke, 2014).

Public-Private Hybrid organizations serving farmer members: The Norwegian Seed

Company (Graminor) has the purpose of breeding crops for Norway and representing foreign varieties (Anon., 2014e). They have 40% of the market share for cereals, 30% for potatoes, and 60% for forages. Ownership is 51% by three farmers coops, 34% by the Ministry of Agriculture, and 15% by a Swedish company. They supply farmers in the coops that own them. Their turnover is 50M NKr ($8M)/year and they have a staff of 30.

Summary

NGO's have working breeding programs and they are fostering new farmer breeders. This activity is provides new cultivars that would otherwise not be available. We provided examples of NGO programs run in conjunction with universities and USDA-ARS who help with scientific backstopping. Cooperative projects address relevance and impact. The art of breeding is an important component that is fostered, possibly by cooperative educational events. The Breeding Institute concept might best follow a model like the SARE program to ensure regional relevance and include NGO's and farmers. Different cooperative models for funding from Europe were presented that address funding private breeders in cooperative activities.

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Response to "What Kind of Partnerships/Models are Working and How Best to Accelerate their Adoption": New Cooperative Models in Plant Breeding by James R Myer

New Cooperative Models in Plant Breeding

James R. Myer[26]

Historical Background to Seed Sharing and Innovation:

For most of recorded history, seed husbandry and selection of crops plants has been a cooperative venture. We presume that similar cultural values were shared by our prehistoric ancestors who first domesticated and refined the crops upon which we now depend. The process was one of growers sharing seeds with friends, neighbors and relatives. Often these seeds had new characteristics that made the variety more attractive or increased their convenience and utility. The shared nature of seeds led to constant innovation as new variation was distributed, recombined and selected over time.

An indication of how rapidly sharing took place is documented by the diffusion of seeds into Europe, as well as globally, as soon as the Columbian exchange began. The first seeds of maize, squash and bean were brought back to Portugal and Spain in 1493. Only a decade later, New World squash was illustrated in Grandes Heures d'Anne de Bretagne (Paris et al., 2006) and about two decades after the initiation of the Columbian exchange, paintings in Villa Farnesina in Rome depicted these New World crops (Janick and Caneva, 2005), signifying their integration into southern European agriculture. Diffusion was equally swift with New World crops introduced into Africa and Asia. In the intervening 500 years, diffusion, recombination and selection has continued, until there are secondary centers of diversity for these and many other crops that have been transported from their place of origins.

From the beginnings of formalized plant breeding to well into the 20th century, seeds have been regarded as belonging to the commons, and culture of sharing seeds was regarded as the Norm. Germplasm exchange was regarded as critical to continued genetic improvement in all crops. However, with the advent of intellectual property protection beginning in the 1970s and continuing to the present time, there has been increasing restriction on formal germplasm sharing (informal exchanges continue although hindered by international plant quarantine regulations). Formal exchanges have not only been limited in peer to peer sharing among breeders, but has led to restrictions in sharing from farmers to breeders, from developing to

[26] Department of Horticulture, Oregon State University, Corvallis, OR 97331. Corresponding author (myersja@hort.oregonstate.edu)

developed countries and from public to private breeders (reciprocal sharing of private to public breeders is almost nonexistent). The process is now formalized with MTAs, patents, and licenses that restrict what can and cannot be done with seed. Plant breeders are concerned about the restrictions on sharing as expressed by the Gouache (2004),Vice President for Scientific Affairs at Limagrain: "*…if today's intellectual property practice had been in place 30 years ago, then it would be very unlikely that US corn yields would have reached today's level.*"

Restrictions on sharing not only affect peer to peer exchange, but limit direct exchange with growers and stakeholders.

The Land Grant University (LGU) model was created in the mid to late 19th century when unrestricted seed sharing was perhaps at its zenith. The idea behind the LGU concept was a democratization of education through the Morrill Act of 1862, the Hatch Act of 1887 and the Smith-Lever Act of 1914. Public plant breeding flourished during this period, where funds were sufficiently stable and in quantity to conduct the long-term research that plant breeding requires, to release finished varieties and to train graduate students for the public and private sector.

Along with the formalization of intellectual property laws and ownership of germplasm has come changes to LGUs. This period of time has also seen growth of the private sector which now has greater influence over agricultural policy at the federal level as well as shaping research priorities in breeding program at LGUs. Funding at LGUs has declined for applied plant breeding positions with a shift from formula funds to competitive grants programs that emphasize short term fundamental research. Policy was shifted at USDA such that plant breeders and geneticists no longer released finished varieties, but rather, were engaged in germplasm enhancement. Until recently, in federal grants programs, USDA considered fundamental molecular projects to be their contribution to plant breeding, even though application has been minimal.

The Contemporary Backdrop for Public Plant Breeding:

Universities seem to be diverging on funding models with consequences for outputs and impacts. Some universities are pursuing federal dollars and academic prestige while neglecting needs of regional agriculture. They risk losing touch with their regional stakeholders and thereby losing the constituency that supports their activities. Other universities continue to embrace the LGU model and work closely with their growers and stakeholders. There seems to be a dichotomy among regions where the agriculture is predominantly commodity crops versus those regions with a high proportion of specialty crops. The decline in agricultural research at LGUs for commodity crops has been particularly rapid as the private sector assumes all of the traditional activities of the university. Symptoms of this process are the regionalization of extension whereby one LGU services several states, and the loss of funding by public researchers from crop commodity commissions because they see their needs covered by industry and public research as increasingly irrelevant. In regions where crops and production systems are diverse, and where industry does not dominate, public research and extension is valued. Because of the regional differences in agriculture and LGU responses, it will be difficult to identify single solutions that can be applied to all regions.

Another troubling trend at LGUs has been a policy that most new faculty hires are either nine month or ¾ time appointments. The expectation is that the individual will find two months of salary from extramural sources to compensate for what is not provided by the university. Not only does this cut in to funds that might otherwise be used to operate a breeding program, but it is demanding of time and increases the pressure of the ticking tenure clock. Nine month appointments in particular do not make much sense for public plant breeders. Most programs are field-based, with the height of activities happening when there is no institutional salary for the faculty member on a nine month appointment. The temptation here is that a faculty member will find that working for the private sector presents the most lucrative opportunity, but the research that they conduct is proprietary and does not necessarily contribute to building a tenurable dossier. I would also contend that this is bad for the university in general because it is at odds with the LGU goals and may alienate stakeholders.

Both the public and private sectors have their own strengths and weaknesses. The public sector can drive innovation through engagement in long term and risky projects. Plant breeding is an eclectic enterprise with breeders borrowing and applying tools and technologies from other disciplines. Public plant breeders are often the innovators in this process. Public plant breeding programs are the main means of training future plant breeders that will work at universities and in industry. The private sector is usually more nimble than the public sector, and can take new technologies and implement them quickly. Seed companies have better infrastructure for getting the word out and disseminating varieties to larger numbers of stakeholders. Where the prime source of conflict seems to lie is the tension between a public program operating in the commons, whereas the private sector wants to restrict access to information to maintain a competitive advantage. Somehow, a balance between the public good and the drive for economic development must be found.

Alternative Models for Public Variety Development:

Since its initial use in international agriculture in the late 20th century, farmer participatory research (FPR) has been employed in both developed and developing countries. We have recently used this model for farmer participatory breeding and trialing in organic vegetable production systems. The main advantages of this approach are a more in depth understanding of the problems, farmers are engaged in the process of breeding new varieties, and the varieties that come out of such programs are highly relevant to the stakeholders. FPR can be more costly than centralized breeding programs, it definitely take more time to organize, and often involves social scientists who facilitate the effort. They may be slower to produce varieties, but what they do produce is highly relevant. Can the FPR model be adapted to contemporary forms of public plant breeding research that integrates all of the players in the seed world?

The key question here is how do we, in this current state of decline in the public plant breeding system and restrictive intellectual property atmosphere, nurture public plant breeding to support stakeholders and the public at large? First, we should reverse the decline in public plant breeding and forums such as Seeds and Breeds are part of the solution because they bring the problem to the attention of the custodians of the purse strings. But other activities are required.

Any new model for public plant breeding should promote secure and stable food systems. In many natural ecosystems, diversity promotes stability, and this can be emulated in food systems. We should put into place models that promote local/regional diversity and innovation. Funding for alternative production systems, such as organic is an important key for diversity. Funding for alternate crops is another potential driver of diversity. Many regional seed companies will give growers more choice than will two or three large multinational seed companies that breed varieties for general adaptation.

Involving growers and other stakeholders in the mix help ensure that breeding efforts are applicable to end users. We have experimented with this model in the Northern Organic Vegetable Improvement Collaborative (NOVIC, 2014) where farmer participatory breeders were involved in variety development and we conducted farmer participatory trials. In an extension of this work we have created the Culinary Breeding Network (CBN, 2014) where chefs are brought in to the network. This provides another level of feedback to the plant breeder in developing varieties that are ultimately interesting and relevant to the general public. In the keynote paper to this session, Mazourek suggests that a nongovernmental organization plant breeding institute integrated with public and private plant breeders is another possible model. With any model, problems remain with how to navigate IP issues, and how to achieve stable funding?

Steps towards a New Paradigm for Public Variety Development:

I would suggest the following as steps that can be taken in the direction of finding and funding alternative models of public plant breeding:

- Return to a system of 12-month appointments for public plant breeders. The nine month/¾ time appointment is a career killer for public breeders and against the interests of LGUs.
- Large multi-institutional, transdisciplinary grants have their place, but for many public plant breeders, collaborations happen on a smaller scale with a sharper focus. Multi-institutional, transdisciplinary grants tend to dilute resources to individual programs and as such, we need more single (or few) investigator grants for public plant breeding.
- We need to investigate models for stable, long-term funding of plant breeding programs. This may include competitive grants (subject to periodic review) that will fund plant breeding programs for 10- year time intervals. Crowd-source funding models need to be investigated.
- We should encourage regional innovation and diversity. The private sector can take care of the status quo, but public plant breeding can engage in risky and long term projects that private industry will not conduct because it may not feed the bottom line.
- We need to investigate collaborative models to engage the public plant breeders and private seed companies with direction and feedback coming from growers and consumers.

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Response to "What Kind of Partnerships/Models are Working and How Best to Accelerate their Adoption": New Models for Funding Decentralized Plant Breeding

by Jared Zystro

New Models for Funding Decentralized Plant Breeding

Jared Zystro[27]

Agriculture is poised for massive shifts in the coming decades. Climate change and the need to reduce the environmental damage resulting from crop production require new methods of farming and new genetics. Participants in this and previous Seeds and Breeds summits rightly see a need to strengthen our public agricultural institutions in order to address these massive challenges. However, are there other resources outside the land grant universities and agricultural research stations? Can we better use the expertise of farmers? In this paper, I will briefly discuss the potential benefits of increasing decentralized, farmer-driven breeding, and I will look at a program that Organic Seed Alliance (OSA) is developing to solve some of the challenges inherent in this style of breeding.

The appeal of participatory and farmer driven breeding

Since essentially all plant breeding is done at a location separate from the farm where the finished cultivars will be used, plant breeding relies on indirect selection. The success of indirect selection depends on how strong the correlation is between selection environment (the nursery) and the target environment (the farm). On-farm breeding, whether through farmer breeder participatory breeding, or farmer breeding, allows for direct rather than indirect selection. A large enough network of on-farm breeders can develop varieties for a wide set of climates and production systems.

Public breeders are a limited resource. In Traxler et al.'s 2005 survey of plant breeders, there were only the equivalent of 637 public scientists working on plant breeding across all crops in the U.S. If 1% of the farmers in this country were willing to devote 10% of their time to plant breeding, that would represent the equivalent of an additional 750 people.

Hurdles

Why don't we see more farmers developing and commercializing new plant varieties? The answer is that lack breeding expertise, economic incentive, and pathways to the market. When farmers are not familiar with the technologies and techniques of plant breeding, any breeding project they undertake will require more time and be less likely to succeed. If the only economic incentive for a farmer to develop a new variety is to benefit their farming operation, relatively few will be willing to make the long-term investments required to carry out

[27] California Research & Education Specialist, Organic Seed Alliance

projects. Finally, even when farmers develop new varieties, the pathways to a market for their varieties is seldom obvious.

How Organic Seed Alliance seeks to address these hurdles

Organic Seed Alliance (OSA) is a non-profit organization with a mission to advance the ethical development and stewardship of the genetic resources of agricultural seed. In our ten-year history, we have devoted considerable effort to conducting breeding projects with farmers and to training farmers in plant breeding. From these efforts, we have seen many successes: scores of farmers trained in basic plant breeding principles, new farm-based seed companies with farmer-bred varieties, and more farmers with varieties they have developed to improve their farm operations. We have done a good job of addressing the first hurdle, that of breeding expertise, and have seen the results. However, in order to scale up the impacts of farmer-breeding, we need to address the second two hurdles: economic incentives and pathways to market.

As part of our strategic plan for the next ten years, we are developing a commercial variety release program, with farmer-bred varieties at the core of the program. We intend to help farmers license their varieties to seed companies. As more farmers get royalties from seed companies for their varieties, we expect a growing number of farmers to take up breeding, eventually increasing the number of varieties that enter the marketplace. This program will offer three key services. First, OSA will manage a variety trial network, so that further commercialization efforts are only spent on truly promising varieties. The second is a matchmaking service, using our connections in the seed industry to match farmer-bred varieties with seed companies likely to be interested in them. The final service is a technology transfer service, managing the negotiations and contracts on behalf of the farmers.

This program helps fulfill OSA's mission, and OSA will additionally benefit from this by distributing its own varieties through this program. However, it is almost certain that it can only be sustainable if we charge for these services, likely as a portion of the royalties. If we are charging, then we need to ensure that the farmer-breeders and seed companies are getting sufficient benefit from the program. This will require a system that is easy to use and delivers results for both sides: substantial returns for the farmer breeders and high quality new varieties for seed companies. If we can accomplish this, we have taken a step towards more decentralized breeding, which, in turn, will help create a more resilient agricultural system in the face of new challenges.

Luncheon Keynote Paper: “Public Cultivar Development and its Role in Responding to Climate Change” by Charles Brummer

CHARLES BRUMMER is the Director of the Forage Improvement Division at the Samuel Roberts Noble Foundation and conducts research on alfalfa and tall fescue breeding and genetics. He received his B.S. degree from Pennsylvania State University and his M.S. and Ph.D. degrees from the University of Georgia. Previously, he was on the faculty at both Iowa State University and the University of Georgia as the forage and bioenergy crop breeder. His program focuses on practical cultivar development, germplasm evaluation and incorporation, breeding methodology improvement, and application of genetic markers into forage breeding. Brummer currently serves as the Editor-in-Chief of the Crop Science Society of America and is an associate editor of Bioenergy Research. He is currently President of the North American Alfalfa Improvement Conference and past-president of the Grass Breeders Conferenc

Public Cultivar Development and its Role in Responding to Climate Change

E. Charles Brummer[28]

What Are the General Issues with Climate Change?

The climate is changing, and while the specific effects of climate change will vary widely among regions, a general propensity toward extreme weather variability is expected. The most commonly invoked issues include warmer temperatures, extended droughts, and more intense rainfall events, but other aspects of climate will also be affected – such as the distribution of precipitation throughout the year. The extreme variability leads to unpredictability, making planning for future agricultural production fraught. The question for us, as plant breeders, farmers, or agricultural professionals, is what can we do to build resilience into our farming systems and into our cultivars so that we simultaneously minimize the possibility of catastrophic loss while maximizing the likelihood of reaching our goals of production, profit, and stability, among others.

[28] Department of Plant Sciences, University of California-Davis, One Shields Ave., Davis, CA 95616. (ecbrummer@ucdavis.edu)

What general roles can plants play in alleviating climate change-induced perturbation and how can plant breeding help?

Plants can substantially affect our environment. Farm and ranch land, urban and suburban residential or commercial areas, athletic fields and public parks, and forests are all managed ecosystems that can be modified to be resilient in the face of perturbation. Management of these systems can have a significant impact on their functionality, and hence, their resilience. Plant breeding can be used to enhance plants used in these systems, and if done in a systematic and rational manner, can be applied to generate an interacting set of species that collectively lead to sustained production, optimal functionality, and minimization of external inputs. We recently published an overarching review of the ways plant breeding can successfully address environmental concern, including that of climate change (Brummer et al., 2012).

Focusing on cropping systems: What types of cropping systems are the most resilient?

In general, we know that more diverse systems – ones that incorporate multiple species both in space and time and that consist of species with different functional characteristics (e.g., grasses and legumes; annuals and perennials) – are more stable and often more productive than simple systems (Brummer, 1998). The clear environmental value of diversity often comes at a cost in management or labor but profitability seems to be little affected (Davis et al. 2012).

If the climate change we are now experiencing is leading to more variable and more extreme weather, then we should be developing and implementing cropping systems that maintain soil cover and increase organic matter content. Systems that accomplish these two objectives – which largely go hand-in-hand – will minimize soil erosion, improve water infiltration and water holding capacity, and therefore, provide a buffer against episodic drought, intense rainfall, and other extremes.

The expected climate changes will expand the ranges of pests, diseases, and weeds, making control problematic, particularly in regions that were previously free of these impediments to production. Therefore, we would be wise to develop and implement cropping systems that limit the emergence of new disease, pest, and weed epidemics and that minimize the impact of these problems if they do arise. We know from the literature that an emergent property of well-constructed, diverse cropping systems is the minimization of disease, pest, and weed problems.

A key component of diverse systems, and one that is sorely lacking in many of the cropping systems in the US, is perennial crops (Glover et al., 2010). Perennials are well suited to maintain soil cover throughout the year. Even when they are dormant during winter in northern regions, perennials are still in place, with roots holding the soil and residual biomass covering the soil surface. Thus, soil erosion and water quality improve with perennials. In addition, perennials will disrupt pest cycles by breaking an annual life cycle under row crops. And in many cases, perennial forage crops like alfalfa show higher profitability than row crops (Olmstead and Brummer, 2008). Filling a somewhat similar niche to perennials are cover crops, which have recently seen a resurgence of interest among farmers of all stripes.

The irony, of course, is that even though "everyone knows" that crop rotation is a good thing, and even though the superiority of diverse cropping systems has been documented since at least Pliny, and continues to be documented in highly controlled scientific experiments (e.g., Davis et al., 2012), we continue to simply our agricultural systems and set up the very instability that we know will arise, particularly as a result of a rapidly changing climate. To at least some extent, this wrong-headed practices is fueled by wrong-headed agricultural policies and subsidies, whether direct payments to farmers for growing certain crops or through subsidized crop insurance programs for those crops.

The depth of subsidization or promotion of an unstable system, say one based on corn (maize) and soybean in the Midwestern USA, is not always obvious. For instance, substantial taxpayer-funded research searches for alternative uses for corn and soybean. Because they are overproduced, "something has to be done" with the products. A more sensible approach may be to find something to do with production of perennial forage crops, for instance, because inclusion of that crop in a rotation would not only improve production of corn and soybean per acre but would also minimize numerous negative consequences of those systems (Olmstead and Brummer, 2008).

Sustainable agriculture supporters often propose new agricultural subsidization programs in the US to support conservation, diversification, etc. The current governmental stagnation in Washington makes the likelihood of new legislation for programs of this type very low. An alternative that could gain support from across the political spectrum is to simply argue for the elimination of current programs. These programs, to a large extent, are subsidizing and promoting the very crops and cropping systems that do the most damage. Ending them could hardly make the situation worse.

What role does plant breeding play within diversified farming systems?

Conceptually, plant breeding is always conducted within the context of a cropping system, whether that's a simple corn-soybean system or a highly complex multispecies rotation. But the selection environment is vitally important, because the pressing production problems for which selection is needed will change depending on the system. A system prone to collapse by recurrent pest problems will necessarily require breeders to continually introduce pest resistances; in a system where such outbreaks are rare, breeders can focus relatively more energy on other traits – say production and nutritive value.

The point I am trying to make is that breeding should be done within the context of a resilient cropping system, and that we should strive to implement resilient cropping systems as a prelude to breeding. Rather than breeding to correct recurrent problems *caused by* the cropping system, let the cropping system *prevent* problems from occurring (and recurring) (Keller and Brummer, 2002). Breeding can then proceed accordingly. Breeding in unstable cropping systems only provides short term fixes and wastes resources on problems that do not need a genetic/breeding fix.

Plant breeding in a changing climate should focus on crops or plants that help foster a successful system known to have resilient properties. This means breeding not only the major grain crops but also cover crops, minor grains, and so on. Second, the right germplasm for future success may be different than that in current breeding programs due to a rapidly changing climate, and accessing and incorporating that germplasm will be necessary. Third, a field-based breeding program is needed to recurrently sample the climate year to year, and these types of programs must continue unabated. Finally, breeders will need to go as fast as possible, bringing all tools to bear on selection, including genetic markers, high throughput phenotyping, and perhaps transgenes or newer genome editing technologies. The focus should be on making stable systems more productive (or more functional, in the case of many horticultural or landscape plants).

What can public breeding do (or propose to do)?

The private sector brings substantial resources to bear on developing major crops for the main growing regions around the world. The private sector – including both small and large firms – is focused on developing commercial products, and the loud debate of biotechnology notwithstanding, this process is based largely on conventional selection and evaluation methods. The breeding industry develops cultivars that are stable over broad regions, that are tolerant to abiotic and biotic stresses, and that have high yield. The industry responds to the market (or to the market as defined by governmental policies), and consequently, focuses breeding effort on those areas most likely to maximize profits. By virtue of widespread testing networks, private industry is undoubtedly producing cultivars of at least some crops that are broadly adapted to current environments. But by focusing on high yield, they may also be setting themselves up for failure under a future of high temperatures and increased drought (Lobell et al., 2014).

The public sector cannot – and really should not – compete directly with the private sector. Numerous niches are not served by the private sector, such as breeding specialty crops, targeting specific environments, incorporating unique traits, and developing cultivars for regional markets. The question, usually, revolves around funding.

The most obvious role of public plant breeders in the academy is education, and training breeders for jobs in private industry is critically important. Funding for graduate students and postdoctoral scientists often comes from competitive grant programs, such as USDA-NIFA or NSF. These programs are not only short-term but also focused on scientific advances rather than continual support for an ongoing cultivar development program. While many genomics and biotechnological tools are developed and basic science knowledge is expanded through these programs – all of which is certainly important for the long-term survival of our food system – these tools, even when directly focused on breeding, are not themselves breeding programs.

Implementation of the tools typically occurs outside of grant funding or after the timeframe of the grant, potentially leaving useful technology waiting to be applied for want of follow-through funding. And further, while development and application of new tools is interesting, the actual need for them in a practical breeding program may be limited, particularly if the cost of their application cannot be recouped through increased seed sales or higher seed prices.

How can we fund public programs to breed system-focused research priorities?

Clearly, in order for public breeding to fulfill the educational needs for future breeders, public breeders need to conduct active breeding programs. For some commodity crops, the small grains being the most obvious, farmer groups themselves fund the breeding programs at universities. While this is continuing, the increase of commercial breeding of these and other crops could diminish this funding stream in the future. Still, if farmer groups are involved in public programs, and public programs are delivering the goods, then this is a nearly optimum situation.

When a grower group does not exist, and a clear mechanism for farmers or other stakeholders to get involved is not developed or unable to be developed for a given crop, then the breeder has several options. First, perhaps the crop or specific niche the breeder is interested in breeding is simply not that important. As academics, we need to be cognizant of the fact that despite our interest in a particular breeding project, it may just not be that important to farmers, consumers, or another set of stakeholders. In this case, other activities may be a more valuable expenditure of public resources.

A second avenue for public breeding program support is to tie the breeding program explicitly with (often, smaller) seed companies. An aversion to industry by public sector breeders is unwarranted; in many cases, outside the major crops mentioned earlier, private industry is needed to get publicly developed cultivars to market, the overarching goal of public breeders. Seed companies may be interested in forming long-term partnerships with public breeding programs, such that breeding objectives are set up jointly early in the cultivar development process. The positive side of such agreements is that a "home" for the ultimate cultivar is likely available at the outset of the program. While these agreements typically require exclusivity, they are usually written to give the company a right of first refusal, so that the public breeder can offer a cultivar to others if the commercial partner ends up not interested in the product. The negative side of these agreements is that some companies can access publicly funded germplasm and others cannot. This is regrettable, yet without funding and/or exclusivity in releases, many publicly developed cultivars would remain on the shelf, which is even more undesirable.

Numerous opportunities to fund public plant breeding outside the normal federal grant or industry contract routes are theoretically possible, but it seems that contacts and relationships need to be built on an individual breeder/plant species basis. The reality that state or federal 'hard money' will continue to diminish seems unlikely to change. Given that reality and given the public good that arises from public breeding programs, breeders need to become ever more savvy in acquiring funding and in making the case that their work is worth the cost. Generating tangible cultivar products is one way to make that case; having them in the marketplace is even better.

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SUMMARY PANEL

Julie Dawson[29] and William Tracy[30]

The issues debated in the present seeds and breeds summit are very similar to those that were discussed 10 years ago at the first DC Summit on Seeds and Breeds for 21st Century Agriculture. Trends at the federal and state levels have not changed to a large extent; however, there are some new themes that emerged at this conference.

Cultivar development in the public interest

Increasingly, the public sector, narrowly defined as plant breeders working for public institutions such as Land-Grant Universities (LGUs) and the Federal Agricultural Research Service (ARS), is not the only source of cultivars developed in the public interest. In the past 10 years, we have seen a tremendous growth in non-profit activities around seed saving and on-farm selection of cultivars with regional adaptation, suited to organic and low-input agriculture. These non-profits include local seed libraries, farmer breeding clubs, regional seed banks such as Native Seeds/Search and national organizations such as the Organic Seed Alliance. Independent seed companies have also grown in recent years to fill the void left by the seed industry consolidation. These companies, organizations and farmer-plant breeders are often focused on regional varieties, varieties adapted to organic systems and crops that have been largely abandoned by the largest multi-national seed companies. They often welcome collaborations for cultivar development with plant breeders at LGUs and ARS.

At the same time, public-sector plant breeding programs at LGUs and ARS are being pushed by funding constraints and institutional pressure to collaborate more closely with the largest seed companies, who often sponsor research and graduate student training programs. While these collaborations produce a source of funds for breeding programs at public institutions, the result is that research is often done in the interests of the private companies, who are best placed to use results of the research they fund and to hire recent graduates trained in these programs. The companies benefit from not having to pay for in-house basic research and training. It also means that public sector research is focused on questions most pressing to the larger seed industry and conventional agriculture. In fact, public plant breeding programs have often been convinced that they will never be competitive with the private sector, so their best chance of staying

[29] Department of Horticulture, University of Wisconsin-Madison
[30] Department of Agronomy, University of Wisconsin-Madison

relevant is to collaborate with private industry that can use public-sector research in private cultivar-development programs. This viewpoint should be challenged, as there are many examples of public plant breeding programs that are producing commercially successful cultivars.

There is a need to define public plant breeding as plant breeding that produces cultivars with a public benefit, whether the cultivar development happens at public institutions such as LGUs or ARS, non-profit organizations, independent seed companies, or as a collaborative effort among these different entities. Public benefits include benefits to the environment, community economic and social capital, and public health. Rather than let ourselves be defined by those who would like to see the public sector do more basic research and training for the private sector, we should work to create competitive choices for farmers in terms of cultivars developed in the public sector.

This would emphasize options for more ecologically based agricultural systems, more sustainable and equitable food systems, and healthier human populations, including perennial agricultural landscapes, varieties for organic management practices, varieties for localized food production, and varieties with improved nutritional quality and flavor. We should look to farmers, non-profits, independent seed companies and consumers that share these goals, as well as researchers focused on agroecology, soil health and other long-term research endeavors that could be aligned with plant breeding for sustainable food production.

There are many organizations at the local, regional, national and international level that are working to improve food systems, human health and the environment, and these would be strong allies for plant breeding programs that focus on these issues. Throughout this conference, the need for more compelling communication about the value of plant breeding was highlighted, as was the opportunity to connect with larger social movements such as environmental conservation, organic agriculture, and food sovereignty.

Sharing valuable genetic resources

Increasing levels of restriction on germplasm and funding sources are isolating public sector plant breeding programs, and slowing down rates of genetic improvement by limiting the effective size of breeding pools for cultivar development. In some crops, it would be very difficult to create a new breeding program, as most elite breeding lines and varieties have associated intellectual property rights that prohibit their use as parents in a breeding program.

Discussion during the conference focused primarily on efforts to prevent the continuing privatization of germplasm resources. These efforts have increased since the last conference, and include both efforts to conserve landraces and other genetic resources and efforts to maintain and encourage exchanges among plant breeding programs working on cultivar development in the public interest. This means keeping cultivars and breeding lines available for future selection, using systems such as plant variety protection (PVP) certificates that permit crossing and seed saving, or releasing populations and cultivars with no intellectual property rights associated with them, such as through the open source seed initiative (OSSI).

Plant breeding has been successful because of the ethic of sharing that existed among plant breeders in the public and private sector. The largest seed companies have abandoned this ethic by patenting newly released varieties and preventing public sector researchers from using them as parents in crosses or even in research trials. In the public sector as well, there is a trend towards more restrictive MTAs with exchanges of breeding lines and other university-developed germplasm. Intellectual property systems such as PVP can return a royalty to the developer of the cultivar, while keeping the cultivar available for continued breeding and research. Utility patents and MTAs that prohibit the use of the as a parental line effectively end sharing and collective innovation.

A plant breeding code of ethics could clearly state the ethic of sharing that has made plant breeding effective at cultivar development and rapid responses to changing environmental conditions. Wheat breeders have had such a code of ethics for decades, and many small grains breeding programs still operate under this framework. This code states that breeding lines exchanged among programs can be used for breeding and seed saving but not for the creation and release of identical or essentially derived cultivars.

A code of ethics common among plant breeders of all species could be functional for work with technology transfer offices at Universities, ARS, non-profit organizations, farmers, independent seed companies, and collaborative projects among multiple entities. Rather than being a new development that needs to supplant the patent system, this code of ethics was in existence prior to PVP and Utility Patent protection for plants and is a strong statement of professional ethics based on based on both the need to recognize and reward innovation and the need to maintain community access to valuable genetic resources.

Defining innovation

Innovation is increasingly being defined in federal grant programs and the public imagination as the use of the newest technologies, whether or not their application to a particular problem is truly novel. This concern was expressed by many participants in the conference, particularly with respect to molecular genetics and genomics technologies. Plant breeders who use phenotypic selection for cultivar development are often not seen as innovative, even though they may be doing scientifically rigorous work that addresses real-world problems in creative ways. An innovation is a new idea or method or product such as a cultivar, and makes appropriate use of both new and existing technologies. Innovation may be deploying new germplasm resources to develop cultivar solutions for more complex agroecosystems, or in developing new methods of selection that require fewer financial resources by improving experimental designs to leverage on-farm observations from decentralized trials.

There is certainly a role for molecular genetics and genomics information in plant breeding, but the use of these technologies should be based on the appropriateness for the particular problem and objectives at hand rather than a perceived need to use these tools in order to be successful at attracting grant funding or publishing. Classical phenotypic selection based on principles of quantitative and population genetics may be a more effective tool to rapidly develop new cultivars with desired traits in many cases.

Cultivar development programs can be very innovative with moderate levels of funding for technical support and infrastructure like research farms and equipment. With this infrastructure in place, competitive grants programs can be used to effectively address specific objectives in cultivar development. Once the infrastructure has been made the responsibility of individual research programs, as is the case at many LGUs, it is virtually impossible to fund cultivar development on competitive research grants, and public sector breeding programs have moved to work on more basic research objectives and have allowed the private sector to control cultivar development.

In the current context of limited state and federally funded research infrastructure for plant breeding, the competitive research grant programs in AFRI have been a good fit for more basic research on genetics and new technologies or methods that use these technologies. This research should not be confused with cultivar development, however. It has been very difficult for grant proposals focused on cultivar development to compete with proposals focused on plant breeding methods using molecular genetic and genomic technologies because of the perception that these types of projects are more innovative and achievable in the short time frame of federal research grant programs.

Conclusion

As the federal and state funding situations are unlikely to change dramatically in the near future, we need to find new models for successful cultivar development, some of which were presented earlier in the conference. There are many new potential partnerships among organizations working in the public interest and socially conscious businesses. Organic farmers were once seen as outdated, but are now considered some of the most innovative farmers in the country. Plant breeders can create innovative solutions for the agricultural systems we would like to see in the future. The best way to convince the public of our relevance to future agricultural systems is to get started and lead by example.

APPENDIX A : Keynote Speaker Biographies

Charles Brummer: "Public Cultivar Development's Role in Responding to Climate Change"

Brummer is the Director of the Forage Improvement Division at the Samuel Roberts Noble Foundation and conducts research on alfalfa and tall fescue breeding and genetics. He received his B.S. degree from the Pennsylvania State University and his M.S. and Ph.D. degrees from the University of Georgia.

Previously, he was on the faculty at both Iowa State University and the University of Georgia as the forage and bioenergy crop breeder. His program focuses on practical cultivar development, germplasm evaluation and incorporation, breeding methodology improvement, and application of genetic markers into forage breeding. Brummer currently serves as the Editor-in-Chief of the Crop Science Society of America and is an associate editor of Bioenergy Research. He is currently President of the North American Alfalfa Improvement Conference and past-president of the Grass Breeders Conference.

Tommy Carter: "The State of Public Cultivar Development"

Carter grew up in rural north Georgia, the son of a county extension agent. His love of plants and agriculture led him to study plant breeding at the University of Georgia and at North Carolina State University, and then pursue a career in soybean breeding with USDA as part of the ARS Soybean Unit located at NCSU. His thirty-two-year career has focused on increasing the impact of the world's genetic resources on agriculture and society. His journal paper describing the narrow genetic base of soybean is the 10th most highly cited article to be published in the journal Crop Science, since its inception in 1960 (Crop Sci. 34:1143, 1994).

Carter has developed 9 soybean cultivars, and 15 germplasm releases. He has served as major advisor to 11 graduate students and committee member to more than 20. Carter has also led a national program of 7 scientists for 10 years to develop drought-tolerant soybean cultivars using germplasm from Asia as parental stock. The original and subsequent drought-tolerant germplasm discoveries by Carter and project members have been the basis for most drought-tolerance advances in U.S. soybean. He identified the first drought-tolerant soybean types and reported the first QTLs for aluminium, salt, and drought tolerance in soybean. He transferred more than 200 breeding lines to industry via MTAs.

David Ellis: "What is the state of our germplasm collections and how best can we utilize and democratize these collections?

Ellis is committed to the preservation of plant genetic resources with decades of experience in academia, private industry and the public sector. He leads the genebank at the International Potato Center (CIP) in Lima, Peru, maintaining the global in-trust collections of potato, sweet potato and Andean root and tuber crop. CIP is among 15 centers of the Consultative Group on International Agricultural Research (CGIAR), dedicated to reducing rural poverty, increasing food security, improving human health and nutrition, and ensuring sustainable management of natural resources.

His research interests span plant development, medicinal compounds in plants (taxol), plant molecular biology, plant and insect ecology, cryobiology and conservation of plant genetic resources and diversity. Ellis has collected Mexican teosinte (the immediate ancestor to maize), worked with native American tribes to preserve plant genetic resources and is currently working with indigenous communities in the Andes.

He previously served on the advisory board for the Desert Legume Program, as past associate editor of In Vitro Cellular & Developmental Biology–Plant, board member for the Society for In Vitro Biology and as a fellow for the Society for In Vitro Biology.

Major Goodman: "Taking the Long View - Changes over time and what is a future course?"

Goodman directs the Department of Crop Science at North Carolina State University. The program focuses on the improvement of maize through the application of quantitative genetics theory and the incorporation of exotic germplasm in traditional maize breeding.

Goodman received a B.S. in Mathematics from Iowa State University, with a minor in Chemistry, and an M.S. and a Ph.D. in Genetics with a minor in Statistics at NCSU. Among his many accolades, he served as a member of the Rockefeller Maize Germplasm Committee in 1972-75, he served as three-fourths chair of the USDA Maize Crop Advisory Committee in 1981-86 and three-fourths chair on the advisory panel for Maize Genetics Stock Center in 1985-86.

Michael Mazourek: "What kind of partnerships/models are working and how best do we accurate their adoption?"

Mazourek is the Calvin Noyes Keeney Professor of Plant Breeding in the Department of Plant Breeding and Genetics at Cornell University. His work focuses on the improvement of peppers, peas and cucurbits (squash, melon, pumpkin, watermelon, cucumber) for growers by increasing yield and production traits, consumers through enhancing flavor and convenience characteristics and the environment through pest and disease resistance that allow reduced pesticide usage. In addition to developing new cultivars with these traits, he trains students in plant genetics and plant breeding and shares these techniques with farmers interested in on-farm participatory breeding. These new seeds are created through traditional cross-pollination techniques and aided by new approaches in genomics that allow insight into the underlying science while still being compatible with certified organic seed. Mazourek received his Ph.D. from Cornell University in 2008.William F. Tracy: "Food Security and the Role of Public Cultivar Development"

Tracy is professor and chairman of the Department of Agronomy, University of Wisconsin-Madison. He served as interim dean of the College of Agricultural and Life Sciences in 2012 and 2013. Tracy received his B.S. and M.S. in Plant Science from the University of Massachusetts-Amherst and a Ph.D. in Plant Breeding from Cornell University in 1982. Following graduation he worked as a corn breeder for the International Plant Research Institute and Cargill, Inc.

In 1984, Tracy joined the department of agronomy as an assistant professor and sweet corn breeder. Tracy leads one of the few remaining public sector sweet corn breeding programs in the U.S. Varieties developed by his program are grown around the world, for both conventional and organic cropping systems. Tracy is current chair of the Maize Crop Germplasm Committee, and president of the board of directors of the International Sweet Corn Development Association.

Kathy Jo Wetter: "What are the key challenges in ownership of seeds and how to best resolve?"

Wetter is the Research Director at ETC Group, an international research and advocacy organization. ETC Group monitors corporate concentration in the ever-expanding sector once known as “life sciences” and tracks emerging technologies and their impacts, or potential impacts, on marginalized communities. For more than 13 years, Wetter has contributed to ETC Group’s research and analysis on the ownership, control, social and environmental impacts of technologies, including nanotechnology, agricultural biotechnologies (e.g., seed sterilization and so-called climate ready crops), synthetic biology and geoengineering. She holds a Ph.D. from the University of North Carolina at Chapel Hill.

APPENDIX B: Panelist Biographies

Jan Ahlen

Ahlen is the Government Relations Representative at the National Farmers Union. Ahlen serves as a link between national and local climate and energy initiatives. He helps to guide grassroots advocacy efforts and advances NFU's policy in Washington, D.C. He works with NFU's other regional coordinators to better educate the general public and decision-makers about the importance of agriculture in solving environmental and economic problems related to threats of energy dependence climate change. His legislative portfolio includes conservation, Renewable Fuels and energy, climate change, forestry, environment, sustainable agriculture, and research.

Charles Brown

Brown is President of Brownseed Farms and Brownseed Genetics. In 1979, he became President of Brownseed Farms, a seed company distributing corn, alfalfa, soybean and field seeds. From 1979 to 2006 the market territory grew to eight states, plus Canada and Eastern Europe, with 400% growth in market capitalization. In 2000 he started Brownseed Genetics with a breeding focus on early maturity and enhanced quality traits. Brownseed Genetics has grown to be one of the largest independent early maturity corn breeding programs in the U.S. It has released a number of lines to the industry and has a commercial or research presence in five foreign countries. Brown has been a long-time member of American Seed Trade Association (ASTA) and Minnesota and Wisconsin WI Crop Improvement Associations. He currently serves as Chairman of ASTA Organic Seed Committee. He was a founding member of US Testing Network, a public-private consortium of breeders, researchers, and seed companies. He is active in the preservation of non-GMO germplasm and a member of Green America, a working group furthering the needs of the non-GMO market segment. He studied Agricultural Economics and Liberal Arts at St. Olaf College, the University of Minnesota and at the University of Reading, Reading England. He also holds a mini-MBA from St. Thomas University, St. Paul.

Ben Burkett

Burkett is a farmer, community activist and President of the National Family Farm Coalition. A former Indian Springs manager of 16 years, he is also current director of the Mississippi Association of Cooperatives, the local arm of The Federation of Southern Cooperatives. Ben represents NFFC on the Via Campesina Food Sovereignty Comission and is a board member of the Community Food Security Coalition (CFSC).The Federation, an umbrella organization now composed of 35 co-ops representing 12,000 African American farm families from Texas to North

Carolina, assists farmers in land retention and the development of economically self-sufficient communities. Burket has traveled to Senegal, South Africa, Kenya, Nicaragua, Lebanon, and Zimbabwe with FSC, exchanging knowledge and information with small-scale farmers. He in turn hosted West African honey, rice and vegetable producers who visited the United States to learn irrigation, marketing and packaging techniques from African American farmers.

Julie Dawson

Dawson is an Assistant Professor in the Department of Horticulture, University of Wisconsin- Madison. Prior to arriving at UW-Madison, she worked on organic and participatory plant breeding projects as a graduate student at Washington State University, and as a postdoctoral researcher at INRA in France and Cornell University.

Jane Dever

Dever grew up on a cotton farm in west Texas. After spending 10 years as Global Cotton Breeding and Development Manager for Bayer CropScience, she returned to Lubbock in 2008 as Associate Professor and Cotton Breeder for Texas A&M AgriLife Research. Her major research focus is development of cultivars for organic production and screening collections for relevant native traits to be used in breeding cotton. Dever received a B.S. in Textile Engineering (1983), M.S. in Crop Science (1986) and Ph.D. in Agronomy (1989) all from Texas Tech University. She previously served as coordinator, Texas A&M AgriLife Extension Service AgriPartners program; Senior Research Scientist, BioTex; Textile Engineer, Plains Cotton Cooperative Association; and Head of Materials Evaluation, Fiber and Biopolymer Research Institute at Texas Tech University. Dever is the Plains and Western chair of the National Cotton Variety Testing Committee, secretary of the CottonGEN steering committee, and served as Associate Editor – Cotton, Journal of Plant Registrations. She was a scientific member of the National Genetic Resources Advisory Council and has served on the Joint Cotton Breeding Policy Committee. She has authored two book chapters, 21 articles, 26 technical bulletins/popular articles, 72 conference proceedings, holds seven patent or invention disclosures and participated in release of more than 30 cotton varieties. Dever is the recipient of the 2012 Cotton Genetics Research Award and the 2012 "Golden Hoe" award presented by the Texas Organic Cotton Marketing Cooperative for outstanding contribution to the organic cotton community.

Steve Diercks

Diercks is owner and operator of Coloma Farms, Inc., an irrigated, 2700-acre family farm in Wisconsin. He and his son, Andy, a fourth-generation potato farmer, grow a variety of potato that they ship around the country. They also grow grain and vegetables.

Brad Gentile

Gentile is the Legislative Director for the office of the Honorable Chris Gibson (US House of Representatives for NY's 19th district (R-NY19). In addition to this role, he was appointed as the Deputy Chief of Staff in March 2014.

Walter Goldstein

Goldstein formed the nonprofit Mandaamin Institute to work for healthy, productive farming and healthy food. Mandaamin is the Algonquian word for corn or the spirit of corn; 'wonder seed.' The institute intends to focus on developing more nutritious corn and wheat and healthier ways of farming. It will continue, deepen, and broaden the work done by Goldstein for 25 years at the Michael Fields Agricultural Institute .

Ferd Hoefner

Hoefner is the Policy Director for the National Sustainable Agriculture Coalition. NSAC is an alliance of grassroots organizations that advocates for federal policy reform to advance the sustainability of agriculture, food systems, natural resources, and rural communities. Hoefner has been NSAC's senior Washington, D.C., representative since 1988. He oversees all of NSAC's federal policy work and has been involved in nearly every federal agricultural budget and appropriations bills, as well as each of the omnibus farm bills, since 1977.

Joy Hought

Hought is Director of Education and Outreach at Native Seeds/SEARCH, a 30-yr-old non-profit seed bank conserving dryland adapted maize, beans, and vegetables from the desert Southwest and northern Mexico. She is also a Research Scientist in the Department of Plant Sciences at the University of Arizona. Hought studied agroecology in Denmark and Norway and has experience in landrace grains, food systems, agricultural history, and participatory breeding.

Kristina Hubbard

Hubbard is the Director of Advocacy and Communications for Organic Seed Alliance, a non-profit organization that advances on-farm, participatory plant breeding and organic seed education and advocacy. She's worked for more than a decade as a researcher, writer, and organizer on seed policy issues.

Fred Kirschenman

Kirschenman is a longtime national and international leader in sustainable agriculture. He currently shares an appointment as Distinguished Fellow for the Leopold Center and as President of Stone Barns Center for Food and Agriculturein Pocantico Hills, New York. He also continues to manage his family's 1,800-acre certified organic farm in south central North Dakota, which has been featured in *National Geographic*, *Business Week*, *Audubon*, the *LA Times* and *Gourmet* magazine. Kirschenman is a professor in the ISU Department of Religion and Philosophy and holds a doctorate in philosophy from the University of Chicago. He has held numerous appointments, including the USDA's National Organic Standards Board and the National Commission on Industrial Farm Animal Production operated by the Johns Hopkins School of Public Health and funded by Pew Charitable Trusts. In April 2010, the University Press of Kentucky published a book of Kirschenmann's essays, *Cultivating an Ecological Conscience: Essays from a Farmer Philosopher*, that trace the evolution of his ecological and farming philosophy over the past 30 years. Kirschenmann served as the Leopold Center's second director from July 2000 to November 2005; he was also one of the first 10 recipients of the James F. Beard Foundation Leadership awards in 2011.

Jack Kloppenburg

Kloppenburg is a Professor in the Department of Community and Environmental Sociology at the University of Wisconsin-Madison. He is the Director of the GreenHouse Residential Learning Community and is affiliated with the Nelson Institute for Environmental Studies and the Agroecology Program. His research has involved study of the social impacts of biotechnology, the emergence of managed grazing networks in Wisconsin's dairy industry, and the global controversy over access to and control over genetic resources. In his work on the "foodshed," he has envisioned the emergence of a sustainable food system founded on local/regional food production, regional reinvestment of capital, local job creation, the strength of community institutions, and direct democratic participation in the local food economy. He is currently excited by the potential of the growing movement for "food sovereignty" and by the possibilities of applying "open source" principles in the biosciences. He is a founder of the REAP Food Group, a non-profit organization working for a just and sustainable food system and, most recently, of the Open Source Seed Initiative (OSSI).

Steve Etka

Etka a native of Virginia, is the owner of Etka Consulting, an Alexandria, Virginia, government relations consulting firm specializing in agriculture and food policy reform. He serves as the Washington Representative for several policy-related coalitions, including the National Organic Coalition (NOC). Prior to forming his consulting business, Etka spent 5½ years on the staff of U.S. Senator Herb Kohl of Wisconsin, serving as Legislative Aide and Deputy Legislative Director, specializing in agriculture, environment, transportation and appropriations matters. Etka graduated from Middlebury College in Vermont in 1987.

Margaret Mellon

Mellon is a respected expert on biotechnology, antibiotics and food safety. She holds a doctorate in molecular biology and a law degree from the University of Virginia. In 1993, Mellon founded the Food and Environment Program at the Union of Concerned Scientists (UCS) to promote the adoption of science-based farming systems that are simultaneously productive, environmentally benign, and resilient in the face of stress. Under Mellon's leadership, the program critically evaluated products of genetic engineering for their contribution to sustainable agriculture and urged the reduction of unnecessary antibiotic use in animal agriculture. After almost 20 years, Mellon stepped down as head of the program in 2012 and after two additional years as a senior scientist, left UCS in 2014. Mellon has published widely on the potential environmental impacts of biotechnology applications. She is co-author of *Ecological Risks of Engineered Crops* and *Hogging It!: Estimates of Antimicrobial Abuse in Livestock* and co-editor of *Now or Never: Serious New Plans to Save a Natural Pest Control.* She served three terms on the U.S. Department of Agriculture's Advisory Committee on Biotechnology and 21st Century Agriculture and for many years taught a popular course in biotechnology and the law at the Vermont Law School. A widely quoted expert on biotechnology, Mellon regularly appears on *ABC World News Tonight*, CNN, and NPR, as well as in the *New York Times*, *Washington Post*, and many other major media outlets. She lectures widely on sustainable agriculture, biotechnology, and antibiotic issues. Mellon is now a science policy consultant in the areas of antibiotics, genetic engineering and sustainable agriculture.

Jim Myers

Myers holds the Baggett-Frazier Endowed Chair of Vegetable Breeding and Genetics in the Department of Horticulture at Oregon State University. He works on a number of crops including dry and snap bean, edible podded pea, broccoli, tomato, winter and summer squash, and sweet corn. Prior to employment at OSU, he worked as a dry bean breeder at University of Idaho. His main interest has been to improve vegetable varieties for disease resistance and human nutrition while maintaining quality and productivity in improved varieties. Myers is also breeding tomatoes, broccoli, and summer squash for organic systems. His latest variety release is the high anthocyanin tomato 'Indigo Rose'.

Julie Obudzinski

Obudzinski is a Senior Policy Specialist at the National Sustainable Agriculture Coalition, a national grassroots organization based in Washington, D.C. that advocates for federal food and farm policy reform. She handles NSAC's research policy work and beginning and minority farmer initiatives. Prior to joining NSAC, Obudzinski worked at the U.S. Department of Agriculture where she coordinated grant programs for organic and specialty crop research, and also at the Leopold Center for Sustainable Agriculture helping to develop a statewide local food policy platform. Originally from Wisconsin, she has lived in the D.C. area since 2006, and has been involved in the region's local food community in many different capacities – including as an apprentice on an organic farm. Obudzinski received her Master's degree in agriculture and food policy from Tufts University in Boston and her Bachelor's degree from the University of Wisconsin.

Theresa Podoll

Podoll farms with her extended family as part of Prairie Road Organic Farm near Fullerton, North Dakota Certified organic since 1977, the Podolls began producing certified organic vegetable seed in 1997, now marketed under the label Prairie Road Organic Seeds. She has been actively involved in the issues surrounding seed access and sovereignty, patenting of genetics, and biodiversity. She serves as a team member of the Northern Plains Sustainable Agriculture Society's Farm Breeding Club.

Ron Rosmann

Rosmann is owner of Rosmann Family Farms in Harlan, Iowa, and is one of over 150 family farmers pioneering the organic meat industry. Although he first farmed conventionally and ran a 1,500-hog confinement operation, Rosmann was always willing to put new ideas to the test. He was an early proponent of crop rotation, and he built his confinement shed to operate on solar power and used straw bedding long before others adopted the practice. In 1990, he started a rotational grazing program with his beef cattle. The farm and its crops, cattle, and hogs intersect with his desire to promote what he calls "rural justice issues." Rosmann believes that if sustainable, organic agriculture can provide a decent living for farm families like his, that it can restore rural life.

Adrienne Shelton

Shelton a graduate student at the University of Wisconsin-Madison. Her research involves developing an open-pollinated sweet corn variety adapted for organic systems using a participatory breeding methodology. Shelton is also exploring the feasibility of "open source" seed licenses and collaborative models within the commercial organic seed industry.

Michael Sligh

Sligh is a founding member of the Rural Advancement Foundation International-USA (RAFI) and directs the Just Foods program. Sligh manages policy, research and education regarding agricultural best practices, agricultural biodiversity, biotechnology, organic identity preservation and a range of food justice and other value-added food labeling, and marketing issues. He has more than 30 years' experience in agricultural practices and policy analysis, including both domestic and international work. Sligh holds the following titles: Founding Chair of the USDA/National Organic Standards Board; Founder of Southern Sustainable Agriculture Working Group; Founder of National Organic Coalition, Founding partner of Agricultural Justice Project, Founding member of Domestic Fair Trade Association. He is also a part-time family farmer and a trained anthropologist. Sligh lives, farms and works in North Carolina.

Margaret E. Smith

Smith came to Cornell University in 1987 as a faculty member in the College of Agriculture and Life Science's Department of Plant Breeding and Genetics, focusing on corn breeding. She currently serves half-time as the Associate Director of the Cornell University New York State Agricultural Experiment Station and half-time in research and extension related to plant breeding. Her research is primarily on field corn, but also includes work on sweet corn. Her program emphasizes breeding for productivity and adaptation to New York growing conditions, improving insect and disease resistance, adapting varieties to more sustainable production systems, and breeding for organic systems. Since 2001, Smith has served as the Department Extension Leader for the Department of Plant Breeding and Genetics. In her extension role, she conducts educational programs for agricultural audiences on crop varieties and seeds, and on plant genetic engineering for diverse public audiences. Before coming to Cornell, Margaret worked for several years in Latin America, first as a plant breeder at the Tropical Agriculture Center for Research and Teaching in Turrialba, Costa Rica, and later as a corn breeder at the International Maize and Wheat Improvement Center in Texcoco, Mexico. The focus of her work in both of these positions was on improving crop varieties for small-scale and subsistence farmers in the tropics – a research interest she maintains to date. She currently collaborates on a plant breeding graduate education project in Ghana.

The Hon. Jon Tester

Jon Tester is a U.S. Senator from Montana (D-MT). He is a third-generation Montana farmer and a former school teacher. He and his wife still farm the same land near the town of Big Sandy, MT, that was homesteaded by his grandparents in 1912. After earning a degree in music from the College of Great Falls, Tester took over the family farm in 1978. Fired up by the Montana Legislature's decision to deregulate Montana's power industry (resulting in higher power costs), Tester ran for and was elected to the Montana Senate in 1998. In 2005, his colleagues chose him to serve as Montana Senate President. He was elected to the U.S. Senate in 2006 and again in 2012.

Jared Zystro

Zystro is Organic Seed Alliance's California Research and Education specialist. He has a Master's degree in plant breeding and plant genetics from the University of Wisconsin. Zystro has worked in the organic seed industry for over 10 years, managing seed production at two farms and conducting research and education projects with OSA. In his work at OSA, he manages OSA's regional development in California, conducts participatory breeding projects and variety trials, and teaches farmers about seed production and plant breeding at workshops, conferences and field days.

APPENDIX C: Cultivar Development Survey

The purpose of this survey is to determine the number public cultivar development programs currently existing at state agricultural experiment stations and how that number compares to the recent past. Our goal is to determine if the number of public cultivar development programs has changed over the last 20 years.

Since USDA-ARS has recently compiled such data for their breeders please do not include USDA-ARS scientists even if they are housed in your department. Thank you.

To encourage transparency, all data will be compiled into national data. No data referring to individual states or experiment stations will ever be published or shared.

Definition: A cultivar development program is a program that creates improved germplasm that is ready to be commercialized. This includes inbreds that will be sold in hybrid combination.

The survey is quite short; it would be very helpful if you could return it by <u>December 20</u>

Survey Questions:

1. University/Department name
2. How many cultivar development programs are in your department?
3. Please list the crops for which faculty/staff in your department are developing market-ready cultivars.
4. Compared to 20 years ago are there more or fewer programs in your department developing market ready cultivars?
5. If the number has changed please estimate how many fewer or more.

APPENDIX D: Plant Breeding Glossary

accession a cataloged item in a gene bank. These can be seeds collected from the wild, landraces and historic varieties and new breeding lines, finished varieties and genetic resources (such as lines developed as sources of disease resistance genes or experimental stocks for genetic research). Accessions can be genetically uniform or heterogeneous depending on the initial collected item and its regeneration history.

additive genetic effect the linear phenotypic change in a trait that occurs from the substitution of one allele for another at a given locus.

allele one form of a gene at a locus. There can be several different forms of a gene in a population, and an individual can have two different forms (one from each parent) if it is a diploid.

Analysis of Variance (ANOVA) a common statistical method used to determine differences between group means for quantitative traits.

anther the pollen bearing male reproductive structure in a flower.

backcross the cross of a progeny individual to one parent or a genetically identical individual.

biennial type of plant that normally produces only vegetative growth the first growing season, overwinters, and then produces a seed crop after which the plant dies. The plant requires two growing seasons to complete its life cycle.

breeding value the value of an individual as a parent based on their additive genetic effects only. The expected average value of the offspring of a given parent for a given trait. Additive effects are used to calculate breeding value because these effects are the portion of genetic variation that parent pass on to their offspring.

composite a cross with multiple parents, made to generate a genetically diverse population and then maintained by normal pollination (either self or cross pollination, depending on the species).

cross pollination reproduction where gametes come from genetically distinct individuals.

crossing over the exchange of segments between chromosomes during meiosis.

cultivar see variety

cytoplasm the contents of a cell between the nucleus and the cell wall. In reproduction, the cytoplasmic constituents from the female parent become part of the cytoplasm of the offspring. There may be a transfer of traits determined by organelles contained in the cytoplasm not associated with chromosomes within the nucleus.

cytoplasmic male sterility (CMS) sterility of the male reproductive organs that is under extranuclear genetic control, usually genetic material in mitochondria or chloroplast organelles. This sterility is inherited maternally. It occurs naturally in many species and has been identified in well over 100 crop species.

dominant allele an allele that produces a given phenotype regardless of whether it is present as a heterozygote or a homozygote (one or two copies at a locus). Dominant alleles, if present as a heterozygote, mask the presence of recessive alleles

dominance effect the difference in the genetic performance of a heterozygote from what would be expected from the average value of the homozygous parents (the additive effects). Heterosis is a type of dominance effect.

environmental variation variation in plant phenotype due to environmental conditions rather than variation due to the plant genotype. In a given location, these can include fixed conditions such as soil type and daylength, as well as variable conditions such as available water, fertility, cultivation practices, and pest and disease pressure.

family a group of genetically related plants. Often the nature of the relationship is specified. As examples, see half-sib families, full-sib families, and S1 families.

family selection selecting individual plants or families based on the overall performance of a family.

filial relating to a generation or the sequence of generations following the parental generation, eg. F1 is the first generation after a cross, F2 is the second generation after a cross.

full-sib family a family structure where plants in a family share the same mother (seed parent) and the same father (pollen parent).

gamete sperm or egg cells resulting from meiosis, containing half the number of chromosomes as the parental plant.

gene the unit of inheritance, located on a chromosome.

genetic drift the random (non-intentional) change in the frequency of alleles in the population as it reproduces over generations. This is important in genetic conservation and in plant breeding, as small population sizes mean that alleles are lost due to drift at a higher rate than in large populations.

genetic marker a DNA sequence variant that can be used to distinguish among individuals with and without a trait of interests. Markers can be linked to single genes or can be neutral (loci that do not have any apparent effect on phenotype). Markers linked to or in functional genes are often used for selection of specific traits controlled by one or a few loci, and neutral markers are often used to study genetic diversity and evolution.

genetic variation the presence of different alleles resulting in different trait values among individuals. Genetic variation is the part of the phenotypic variation that can be attributed to genetic causes. Other causes of phenotypic variation include environmental influences on traits and the interaction between an individual's genetic makeup and the environment.

genomic selection the use of high density genome-wide genetic markers to predict phenotypic performance of breeding lines and select individuals for crossing or trialling, generally using regression models to predict phenotype from genotype or to improve the accuracy of phenotypic data by adjusting estimates of performance with information from genetically related individuals.

genotype the genetic identity of an individual.

genotype by environment interaction, GxE a differential response of genotypes to changes in environmental conditions. GxE can be scalar, meaning that some genotypes respond to a change in environments more than others but there is no change in genotype performance rankings, or GxE can be crossover, meaning that genotypes respond differently to environmental conditions resulting in a change in genotype performance ranks across environments.

genotyping by sequencing (GBS) a method of producing inexpensive high density genetic markers using DNA sequencing.

germplasm the entire collection of genetic material for any given crop species. This includes elite cultivars, breeding lines, historic varieties, landraces, and wild relatives that can be crossed to the crop species.

half-sib family a family structure where the plants in a family share the same mother (seed parent) but have different fathers (pollen parents).

heredity the transmission of genetic characters from parents to progeny.

heritability the proportion of observed variation in the progeny that is inherited.

heterosis or hybrid vigor the increase in vigor of hybrids over their parental types

heterozygous an individual that has unlike alleles present at particular locus.

homozygous an individual that has like alleles present at the loci of interest

hybrid the product of a cross between genetically distinct parents.

hybridization crossing of individuals with different genotypes to achieve genetic recombination.

ideotype an imagined crop variety representing the ideal to be reached through a breeding project.

inbred a variety produced by successive inbreeding over a number of generations. Also called an inbred line. The same concept as pure line, but the term inbred is generally used for naturally outcrossing crops and pure line is used for naturally selfing crops.

inbreeding depression decrease in fitness due to inbreeding. Inbreeding depression is generally severe in outcrossing species such as maize and not significant in naturally selfing species such as wheat.

intermate cross-pollination between individual plants.

isolation distance the required distance to isolate seed crops from other crops of the same species that may be a source of pollen or seed contamination.

landrace a genetically and physically diverse variety that has developed over time by adaptation to the natural and cultural environment in which it exists.

line a group of individuals from a common ancestry. Used to designate different selections or varietal candidates within breeding programs. Purelines or inbred lines are genetically homozygous and true-breeding.

linkage a correlation in the inheritance of two or more genes; deviation from independent inheritance of those genes. The tendency of genes that are located near each other on a chromosome to be inherited together.

linkage disequilibrium the occurrence of combinations of linked alleles in a population in frequencies different from what would be expected based on random (independent) assortment.

linkage drag undesired changes in a trait under selection because unfavorable alleles at genetic loci for that trait are linked to desirable alleles at genetic loci for another trait. Often used in the context of disease resistance, as favorable resistant alleles from wild species or landraces may result in a decrease in yield or quality when crossed to elite lines.

locus the location of a gene on a chromosome. Plural: loci

male sterility an inherited factor useful in hybrid seed production. It prevents viable pollen from being produced.

marker assisted selection the use of genetic markers to select individuals in a breeding program. Markers can be linked to single genes (ie. for disease resistance) or can be used as a genetic fingerprint of an individual for use in statistical methods of selection for quantitative traits (see genomic selection).

mass selection a form of selection where individual plants are selected based on their individual performance. Stratified mass selection uses a gridded approach to mass selection, selecting the best plants from each subsection of the field in order to avoid selecting primarily on environmentally-induced variation.

meiosis the process of cell division that produces sperm and egg cells.

monogenic a trait that is controlled by a single gene.

multiline a variety formed by the combination of two or more lines.

MTA material transfer agreement. A contract commonly used in exchanging breeding lines, signed by both parties and defining the permitted uses for the seed.

natural selection the process by which populations change due to individuals within the population that are better adapted to their environment tending to survive and produce more offspring.

negative selection selection against undesired traits, typically removing only a small fraction of the population.

nursery a field designated for rearing and testing breeding stock, performing crosses and other breeding activities.

nuclear restorer genes these are nuclear genes that can restore fertility in plants with cytoplasmic male sterility (CMS). These genes are usually dominant in their expression and when present will restore male fertility to plants with CMS. These genes are often abundant in wild populations of plants with naturally occurring CMS.

open-pollinated (OP) in an outcrossing species, seed produced as a result of natural pollination as opposed to hybrid seed produced as a result of a controlled pollination.

outcrossing a population or species where natural reproduction is through cross-pollination (mating of genetically distinct individuals.

plant variety protection (PVP) Plant Variety Protection Act of 1970 established a form of intellectual property protection for seed-propagated varieties, which were excluded from the 1930 Plant Patent Act. A PVP certificate gives the breeder the right to exclude others from selling the variety, propagating the variety as a step toward commercial sale or marketing, using the variety to produce an F1 hybrid, or exporting the variety. Important exemptions exist for research, where plant breeders are allowed to use varieties under PVP as parents in crossing, and for farmers, who may save their own seed varieties under PVP.

passport data the information provided with a genebank accession, usually species, variety name and pedigree if available, cultivated or wild status, collection site/geographic origin or breeder, some basic information on phenotype if the accession has been characterized, and potentially publications involving the accession and intellectual property rights on the accession, as well as whether the accession is available for distribution.

phenotype the visual characteristics of an individual. The phenotype is a combination of genetic and environmental factors, including potential interactions between the genotype and the environment.

plant patent established by the Plant Patent Act of 1930, applicable to any distinct and new variety that is propagated asexually, other than by tubers. The holder has the right to exclude others from asexually reproducing the plant and from offering it for sale.

progeny the offspring of an individual or cross.

pollination the transfer of pollen from the anther (male part of the flower) to the stigma (female part of the flower). Pollination precedes fertilization, the fusion of sperm and egg to form a zygote.

polygenic trait relating to or controlled by multiple genes. When the number of genes gets large, traits are referred to as quantitative.

population a community of individuals within a species that can intermate. A population shares a common gene pool.

positive selection selection for beneficial traits, typically removing a majority of the population.

pureline in selfing species, a genetically uniform variety developed by selecting a series of superior individual plants from a single cross.

quantitative trait a trait controlled by a large number of genes, where continuous phenotypic variation for the trait is observed (such as yield), rather than discrete phenotypic classes (such as spines on yellow squash). Quantitative traits also often display environmental variation and genotype by environment interactions.

recessive allele an allele that produces a given phenotype only when it is present as a homozygote (two copies at a locus).

recombination formation of new genetic combinations in progeny of a cross.

reciprocal cross two mirrored crosses made between a single set of parents where each parent serves as both the female and the male.

regeneration planting out and multiplying seed of an accession. This is usually done on a fixed timeline, to avoid losing accessions due to loss of viability in storage. Regeneration practices vary by species but the goal is to maintain the accession as it was collected in terms of its phenotypic identity and genetic composition.

rogue removal of a small fraction of undesirable individuals from a population.

S1 (etc) symbol designating the first generation after a self-pollination.

S1 family a family structure where the plants in the family all resulted from the same self-pollination.

self-pollination reproduction where both gametes come from the same individual. This is an extreme form of inbreeding.

S1 family a family structure where the plants in the family all resulted from the same self-pollination.

selection the process of determining which individuals in a population will genetically contribute to the next generation.

self-incompatibility a general name for several genetic mechanisms that prevent self-fertilization. Self-incompatibility can also limit cross-fertilization between closely related plants.

selection intensity the proportion of the population that is selected to advance to the next generation.

selection differential the difference between the initial population mean and the mean of the selected individuals.

specific adaptation occurs when there is a consistent pattern of genotype by environment interaction, where a given genotype or population performs better than other genotypes or populations in a specific environment, and performs worse than those populations in other environments.

target population of environments (TPE) the set of environments (farms and future seasons) in which the varieties produced by a breeding program will be grown.

trait a characteristic of interest to the breeder. Traits can be very simple, controlled by one or a few genes (qualitative), or they can be complex and controlled by many genetic and environmental factors (quantitative).

UPOV l'Union pour la Protection des Obtentions V´eg´etales (The International Union for the Protection of New Varieties of Plants) was established in 1961 in Paris and came into force in 1968 when ratified by the UK, the Netherlands and Germany. There was a major revision in 1991 that strengthened protection for varieties. Some countries use the UPOV 1961 rules and others use the 1991 rules.

utility patent The utility patent is a standard patent, established in 1793. Inventions must be new, useful, and non-obvious. A utility patents confers right to exclude others from making, using or selling the invention, with no statutory exemptions for research, breeding or seed saving.

variety a group of plants of a particular species that shares a set of characteristics or traits that differentiates it from other varieties of the same crop. These characteristics must be distinct and relatively uniform across all of the plants of the variety. Variety is a synonym for cultivar.

wide (or broad) adaptation the ability of a given genotype or population to perform well across many different environments. This stability is usually me relative to the average performance of all genotypes or populations measured, rather than in absolute trait values. A genotype with broad adaptation would consistently outperform other genotypes in the trial across environments.

APPENDIX E: List of Summit Attendees

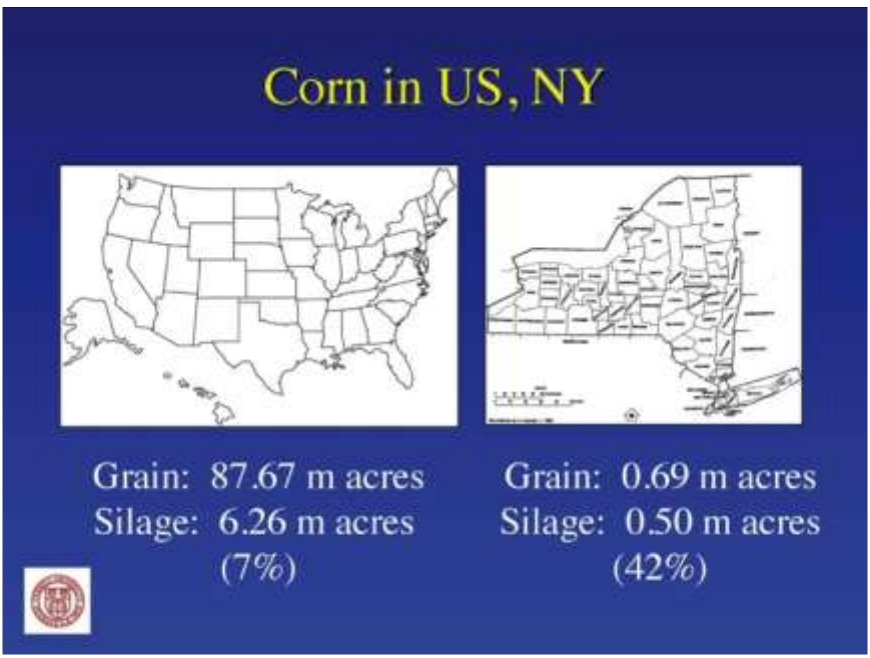
Jan	Ahlen	National Farmers Union
Daniel	Brito	Union of Concerned Scientists
Charles	Brown	Brownseed Genetics Inc.
Charles	Brummer	The Samuel Roberts Noble Foundation
Ben	Burkett	Individual
Thomas	Carter	USDA
James	Coors	University of Wisconsin at Madison
Julie	Dawson	University of Wisconsin at Madison
Kelly	Day-Rubenstein	USDA
Jane	Dever	Texas A&M University
Steve	Diercks	Coloma Farms Inc
David	Ellis	International Potato Center
Steven	Etka	National Organic Coalition
Paul	Gepts	University of California at Davis
Christopher	Gibson	U.S. House of Representatives
Michael	Glos	Cornell University
Walter	Goldstein	Mandaamin Institute
Major	Goodman	North Carolina State University (NCSU)
Kenneth	Greene	Hudson Valley Seed Library
Lisa	Griffith	National Family Farm Coalition
Doug	Gurian-Sherman	Union of Concerned Scientists
Paul	Heisey	USDA
Ferdinand	Hoefner	National Sustainable Agriculture

		Coalition
Joy	Hought	Native Seeds/SEARCH
Kristina	Hubbard	Organic Seed Alliance
Alfredo	Huerta	Miami University
Adbullah	Jaradat	USDA
Marni	Karlin	Individual
Fred	Kirschenmann	Individual
Jack	Kloppenburg	University of Wisconsin at Madison
Joe	Kowalke	Double Forte
Lisa	Kucek	Cornell University
Daryn	Lane	Individual
Mark	Lipson	USDA
Richard	Little	University of Nebraska
Claire	Luby	University of Wisconsin at Madison
Jeremy	Machacek	USDA
Scott	Marlow	Rural Advancement Foundation International-USA
Michael	Mazourek	Cornell University
Margaret	Mellon	Individual
Kathleen	Merrigan	USDA
James	Myers	Oregon State University

Juli	Obudzinski	National Sustainable Agriculture Coalition
Kathy	Ozer	National Family Farm Coalition
Tessa	Peters	University of Wisconsin at Madison
Thao	Pham	Clif Bar Family Foundation
Theresa	Podoll	Individual
Charlotte	Pool	The Samuel Roberts Noble Foundation
Richard	Pratt	New Mexico State Univesity
Elia	Romano	Albert Lea Seed
Ronald	Rosmann	Rosmann Family Farms
Mark	Rosmann	U.S. Department of State
Adrienne	Shelton	University of Wisconsin at Madison
Michael	Sligh	Rural Advancement Foundation International-USA
Margaret	Smith Einarson	Cornell University
Stephanie	Strom	The New York Times
Jon	Tester	Individual
Ann Marie	Thro	USDA
Steven	Todd	USDA
William	Tracy	University of Wisconsin at Madison
Herman	Warren	Individual

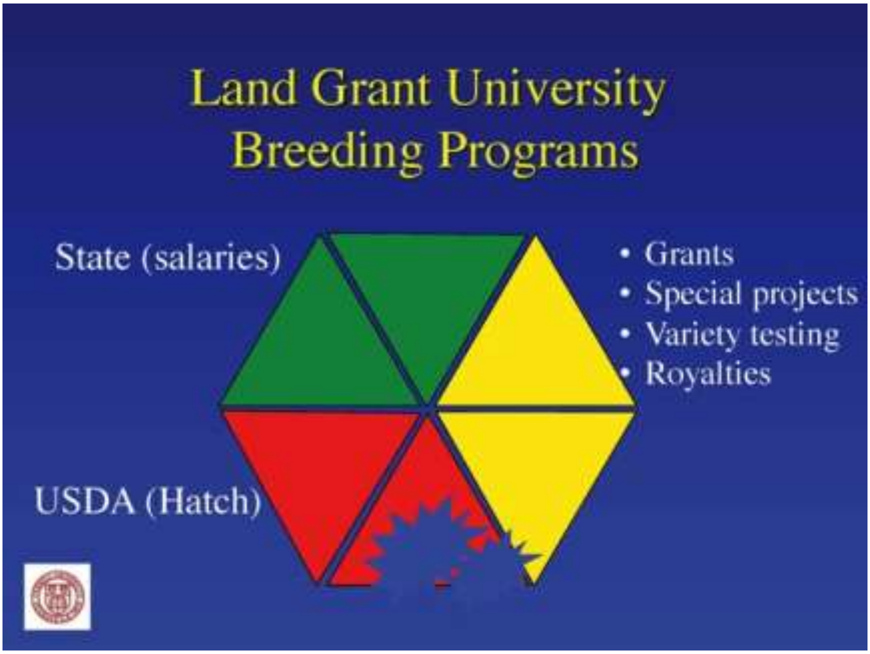
Kathy Jo	Wetter	ETC Group
Jared	Zystro	Organic Seed Alliance

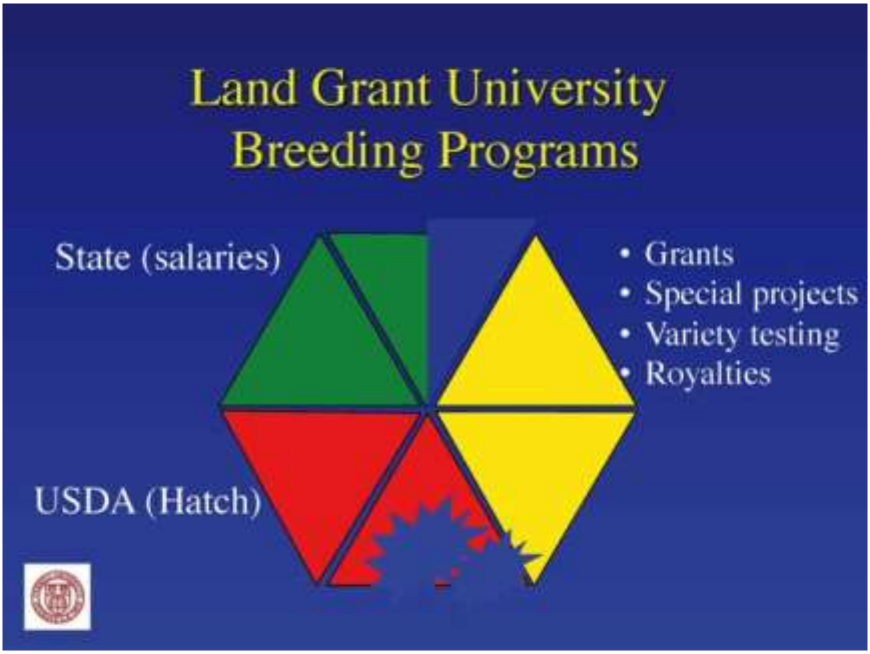
APPENDIX F: Presentations & Slideshows




Land Grant University
Breeding Program Trajectory
State (salaries)
USDA (Hatch)
• Grants
• Check-offs
• Special projects


Land Grant University
Breeding Programs
State (salaries)
• Grants
• Check-offs
• Special projects
• Variety testing
USDA (Hatch)


Land Grant University
Breeding Programs
State (salaries)
USDA (Hatch)
• Grants
• Special projects
• Variety testing
• Royalties


Land Grant University
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• Special projects
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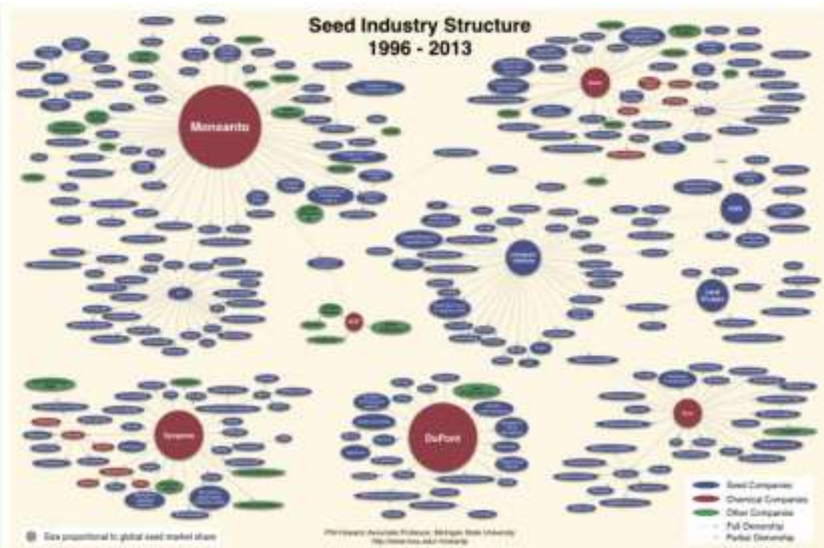
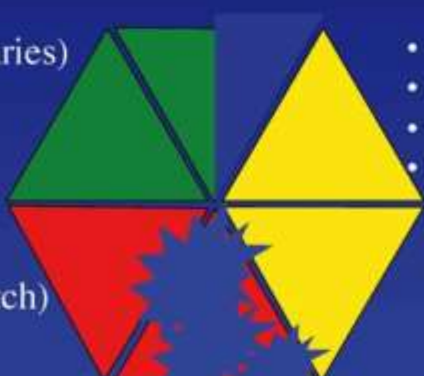


2013, Philip Howard, Michigan State University

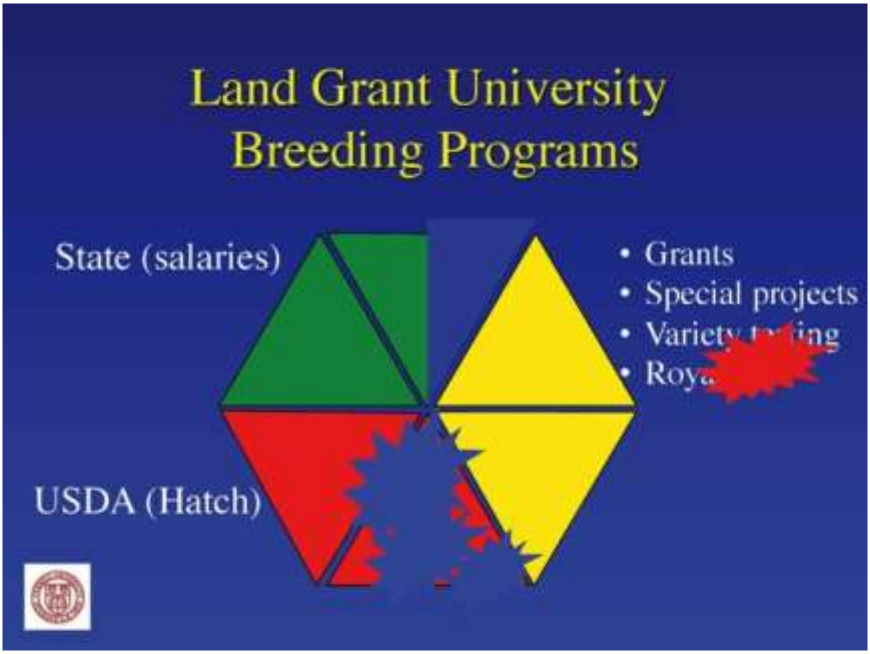
Land Grant University Breeding Programs

State (salaries)

- Grants
- Special projects
- Variety testing
- Royalties



USDA (Hatch)


Land Grant University
Breeding Programs
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USDA (Hatch)
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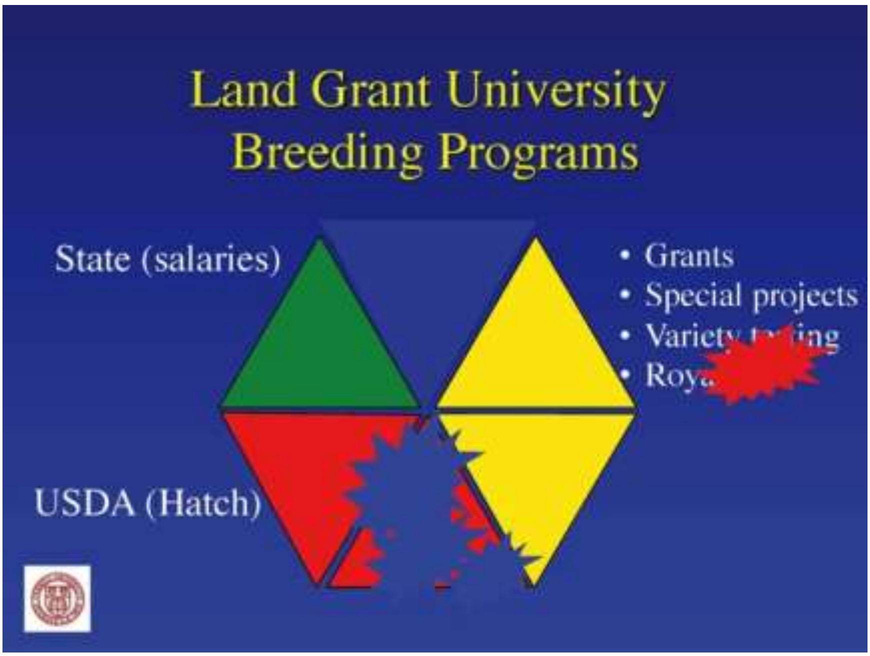
• Special projects


Land Grant University
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USDA (Hatch)
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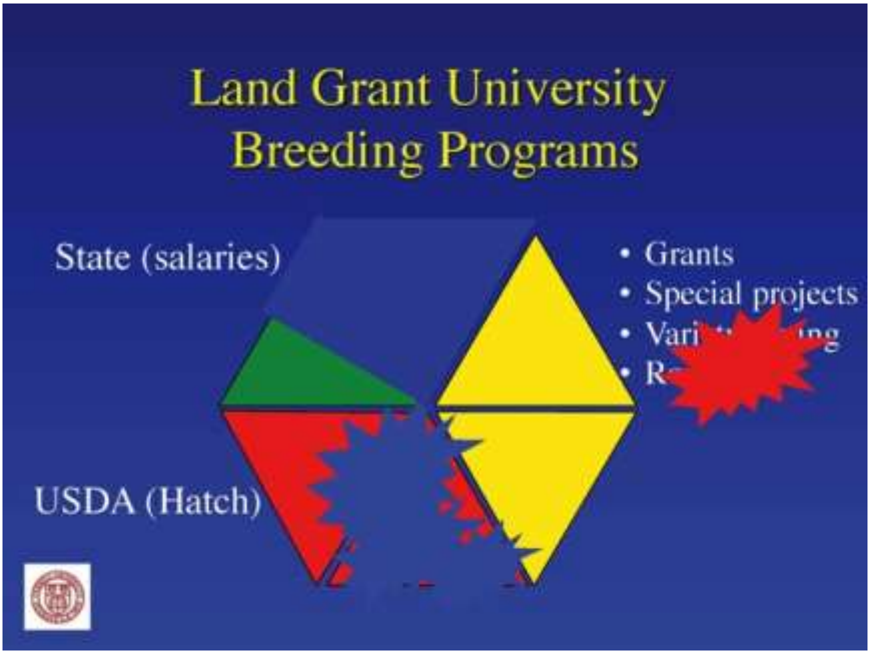
Land Grant University
Breeding Programs
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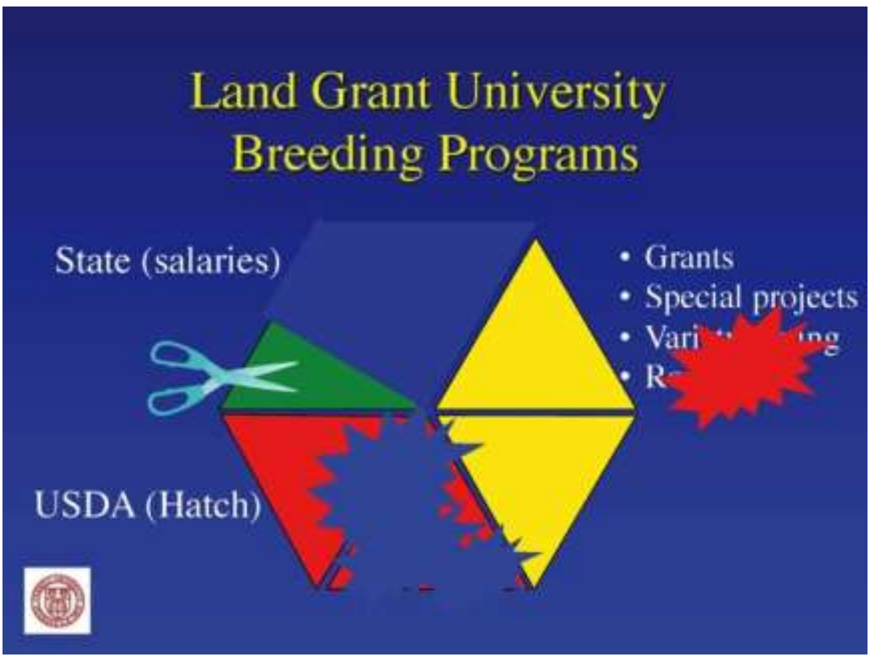
Land Grant University
Breeding Programs
State (salaries)
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Response to this pressure
• US Germplasm Enhancement of Maize
– $500,000 in 1995
– Grew to $1.3 m
GEM


Response to this pressure
• US Germplasm Enhancement of Maize
– $500,000 in 1995
– Grew to $1.3 m
– 1996: 15 public cooperators
– 2004: 14 public cooperators
– 2012: 4 public cooperators
– 2013: 0 public cooperators
GEM

Response to this pressure

- US Testing Network
  - 27 private and public members
  - 41 locations in 11 states in 2012
  - Conventional and organic
  - Maturity range 80 – 115 days RM

USTN
US Testing Network

So what do we really need?

- Commodity and industry support
  - Check-offs, scholarships, grants
  - Lobbying with policy-makers
- Capacity funds for long term
  - "Arc of research"
  - How to structure and administer?
    - "National Board" that C. Brown suggests?
- Re-thinking by public sector administrators
  - Royalties, variety testing, management tasks


So what do we really need?


So what do we really need?