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COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

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Chairwoman Comstock, Ranking Member Lipinski, and members of the Subcommittee, thank you for the opportunity to participate in this important discussion today.

I am currently a Professor of Maize Breeding and Genetics, in the Department of Crop Sciences at the University of Illinois. Crop Sciences is housed in the College of Agriculture, Consumer, and Environmental Sciences, but I also have long-standing collaborations with our Institute for Genomic Biology and many other campus groups. I lead a research, education, and outreach program that focuses on genomic applications to crop improvement, in particular "big grasses" such as corn, sorghum, and more recently *Miscanthus* as a potential dedicated bioenergy crop (http://mooselab.cropsci.illinois.edu/). My laboratory group sequences plant genomes, designs and builds variations into these genomes using breeding and biotechnology approaches, and then evaluates the performance of these genomes in the field. Our largest project is aimed at solving the genetic mysteries of hybrid vigor and nitrogen use efficiency in corn. I have taught courses in plant biotechnology and genomics for each of the past 18 years, where hundreds of students actively learn how to translate discovery into innovation. I am also active in service to my profession, for example as a member of the Advisory Board for the Department of Energy's Joint Genome Institute, and to the broader public, through presentations about crop biotechnology to a diversity of audiences.

I also come to you today with a strong personal commitment to today's topic, "*Putting Food on the Table…*". I was raised on a farm of dairy, honey, and hay. I first learned about genetics when I was 14, and became sufficiently fascinated with it to make it my career. I attended Case Western Reserve University, the only school in Ohio at that time which offered an undergraduate degree in biotechnology. I earned my doctorate at North Carolina State University, through the support of a graduate fellowship sponsored by the state of North Carolina. Even better, they also recruited my future wife, Shawn Carlson, to Raleigh. Shawn's family farms 1500 acres of dry beans and other crops in Michigan, including direct marketing to restaurants and stores. Once we farmers became scientists, we then began our journey to bring science back to the farm. We have done this through positions in both the crop biotechnology industry and universities, from California to Connecticut, and back to the Midwest. I share my story with you because it emphasizes my thoughts about the topics you invited me to discuss with you today. I am a living product of valuable contributions from local, state and federal governments, as well as strong partnerships among farmers, universities, and the private sector. ***Together, agricultural research connects farmers and scientists, and brings innovation back to the farm.*** These combined efforts have powered tremendous advances in agriculture that enable farmers to meet world demands for nutrition and the bioeconomy, and represent a solid foundation for future research and innovation with global impact. Simply stated, our agricultural research system is the envy of the world, with substantial benefits to U.S. citizens and the world.

I was invited to discuss with you the following three topics:

- Agriculture research efforts at the federal, state, and local government levels.
- The extent to which federally funded researchers at universities and other research institutions are partnering with the private sector, including with farmers, to advance agricultural research;
- The value of agricultural research and implications for the nation and world.

For each, I will highlight how past innovation has revolutionized society and our quality of life, and link these to future prospects for creating further value through agricultural research. For brevity, my examples will emphasize corn genetics, a truly American science, but I am here before you today as only one representative for the broader agricultural research ecosystem. This includes not only crops and livestock, but also engineering, food processing, economics, and environmental science. In each of these disciplines, agricultural research connects the farmer to science and scientists to farmers. Because of the strong public interest in food, agricultural research also engages society with both scientists and farmers, in ways that enrich all of our lives.

Agriculture research efforts at the federal, state, and local government levels

Formalized government investment in agricultural research in the United States was sprouted in the rich prairies of Illinois. One of our country's greatest Presidents, Abraham Lincoln, signed into law the creation of the "People's Department" the United States Department of Agriculture (USDA), as well as the National Academies of Science (since expanded into National Academies of Medicine and Engineering), and through the Morrill Act, land-grant universities. From their onset and continuing to the present, land-grant universities such as the University of Illinois have served as the core of shared investment between states and the federal government to support agricultural research. The products from these engines of discovery have made our country the unquestioned world leader in science and innovation for agriculture.

American leadership in agricultural research is founded on an extensive network of national support. Federal funding comes through a variety of institutions, including national or regional laboratories managed by the Departments of Agriculture or Energy, capacity-building through the Hatch Act, competitive grant programs, and dedicated investments for specific research needs deemed important by the taxpaying public. An example of the latter would be the national network of USDA germplasm centers, some of which are embedded on campuses such as the University of Illinois with the Maize Genetics Cooperation Stock Center. The largest piece of this federal agricultural research "pie" is distributed through competitive grant programs administered by the USDA (National Institute for Food and Agriculture and Foundation for Food and Agriculture Research), the National Science Foundation (many programs) and the Department of Energy (Biological and Environmental Research and ARPA-E). The majority of these federal dollars support research at universities, both public and private, and including every land-grant university in the nation. Federal funding supports a healthy diversity of research projects, from small exploration grants to large multi-institutional centers. Furthermore, agricultural research is one topic where different agencies have created valuable partnerships. Two specific examples with which I have been involved include the Interagency Working Group on Plant Genomes (https://nifa.usda.gov/sites/default/files/resources/plant_genome_init.pdf), and the USDA-DOE Plant Feedstocks Genomics for Bioenergy.

Building on the successes and impact of the above cooperative federal investments, state and local governments also provide critical support for agricultural research of regional relevance. In addition to their substantial funding to land-grant universities, many states include agricultural research in their budgets. It is important to emphasize that due to the diversity of climates and agricultural systems in our country, broad geographic representation is an important facet of our research network. States and local communities also partner extensively on technology transfer and business development, through agriculture innovation districts such as the Research Triangle Park in North Carolina, and 39 North in St. Louis. Universities are often the nucleus for such districts, and link great ideas with startup business skills, the early-stage business investment community, and job growth. Two notable examples of successful companies that were nurtured in our own Illinois Research Park include iCyt and their novel technologies for rapid genetic typing of livestock, and Chromatin, one of the first synthetic biology companies for crop plants.

Abraham Lincoln's vision considered agricultural research and education fundamentally linked. Modeled after what is now known as Michigan State University, the Morril Act created the public land-grant universities for teaching agriculture, and brought engineering to American colleges. This year, the University of Illinois at Urbana-Champaign celebrates 150 years of teaching farmers to become scientists and scientists to study the farm, facilitating the exchange of knowledge to improve agriculture. Our students earn undergraduate and graduate degrees in many disciplines, including engineering, business, the life and environmental sciences, health and community development. They become the next generation of researchers and a well-trained workforce. Importantly, the quality of student education is enriched by substantial federal and state support for faculty, infrastructure, research costs and student aid. NSF, USDA, and DOE each support fellowships for graduate education and research training, research experiences for undergraduate students, and additional training for the most promising postdoctoral scientists. We professors also do not stop teaching when the tassels turn at graduation. All grants awarded by the NSF must foster broader impacts, which in many cases include outreach programs to actively connect scientists, the public, and agriculture. At Illinois we formalize this in our annual Corn Breeders' School, where industry professionals return to the "classroom" for two days to network and be updated on latest advances.

On our university campuses, we also develop future leaders of the agricultural research enterprise. Importantly, the land-grant mission has always embraced the under-served, with a historical emphasis on rural citizens, but now expanding to urban communities. In my specific discipline, the University of Illinois launched the careers of both Dr. Robert Fraley and Dr. Mary Dell-Chilton, pioneers of the agricultural biotechnology industry, and many other important leaders of academic and industry research. At my institution, Dr. Robert Jones was raised in a sharecropping family, progressed through the land grant system as a student, professor, and is now the Chancellor at the land-grant university in Lincoln's home state. The farmer became a scientist. And my current Dean, Dr. Kimberlee Kidwell, gained her passion for plant breeding as an undergraduate student at Illinois with Dr. John Laughnan, who discovered that truly delicious American treat known as Illini SuperSweet corn. The scientist became a farmer.

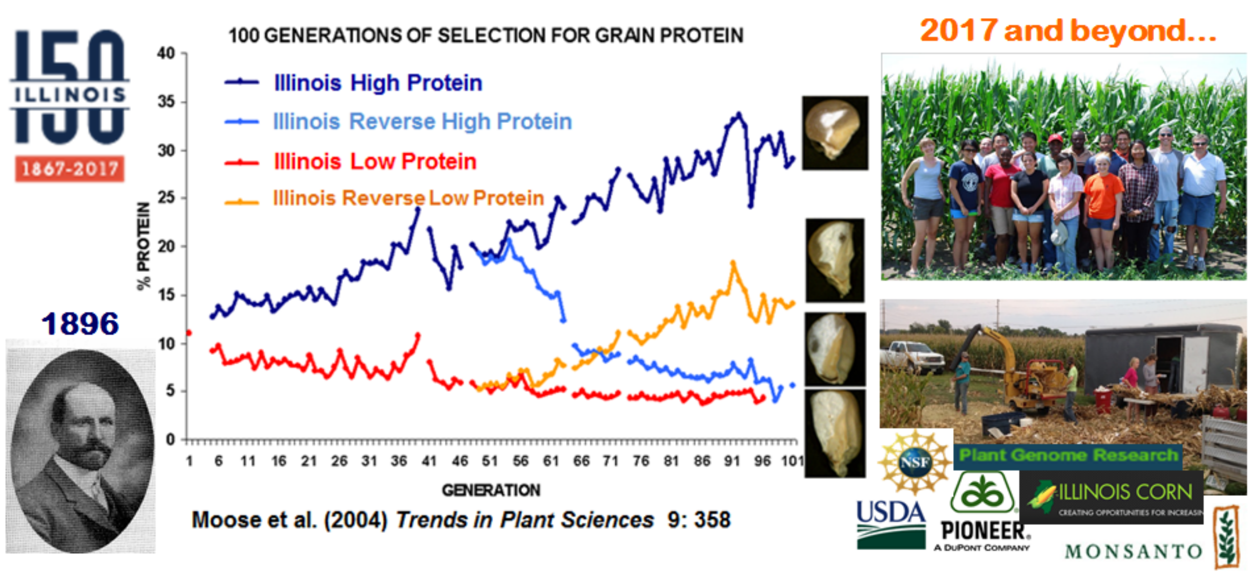

Figure 1: The Illinois Long Term Selection for grain protein in corn seeds. Starting with ears collected from a local farm in 1896, more than a century of breeding has produced the known extremes for grain protein and a suite of correlated nitrogen use efficiency traits. Today, my team of scientists and students studies the genetics of this experiment, with the support from government agencies, leading companies, and farmer groups.

The extent to which federally funded researchers at universities and other research institutions are partnering with the private sector, including with farmers, to advance agricultural research;

The above already touches on a key message regarding partnerships to advance agricultural research among universities, the private sector, and farmers. There is a long history of cooperation among all across the agricultural sector, which now forms a robust network for new discoveries and their application. I first illustrate by an example from my own federally-funded research, which continues to learn from the longest running continuous plant genetics experiment in the world.

Dr. Cyril Hopkins was the Head of the very first Department of Agronomy in the nation, at the University of Illinois. Having read Charles Darwin's books on natural selection, Dr. Hopkins wondered if those principles could be applied to improving the nutrition of corn kernels. Dr. Hopkins obtained ears of corn from a local farmer, and with the help of his graduate student Edward East, initiated experiments to select corn with the highest or lowest concentration of seed protein. A similar experiment was started for high and low seed oil. The experiment has been conducted nearly every year since, with my current team of students just completing the 120th cycle of selection (http://mooselab.cropsci.illinois.edu/longterm.html). Research performed on the experiment over the years has demonstrated the power of breeding and selection to change plant traits, has revealed the genetic control of seed nutritional quality, and more recently has enabled the discovery of genes that improve nitrogen use efficiency in corn.

From its beginning and throughout its history, there has been active collaboration with both farmers and seed companies. The earliest corn hybrids used the Illinois germplasm as parents. The high oil selections form the basis for hybrids that have been marketed since the 1990s for their enhanced nutritional value as animal feed. The NSF Plant Genome Research Program and USDA have funded genomic studies of the selected populations, which reveals genes that program the remarkable trait variation that is observed. Both DuPont Pioneer and Monsanto have supported research on the experiment to better understand plant breeding principles and how corn plants acquire and use nitrogen. In addition, hundreds of students have gained direct breeding experience as caretakers of this unique genetic resource. Some of these students were supported by the Illinois Plant Breeding Center (http://plantbreeding.illinois.edu/), where seed companies invest in education and research training of future scientists. Most recently, the farmer-supported Illinois Corn Marketing Board has generously provided graduate fellowships to sponsor students who continue the selection experiment, and to participate in a broader national network for public sector corn genetic improvement, the Genomes 2 Fields project.

The above is just one personal example. There are many similar stories from across the nation that involve long-term partnerships among federally-supported university researchers, the private sector, and farmers. Some additional highlights involving the University of Illinois:

- **"Using Precision Technology in On-Farm Field Trials to Enable Data-Intensive Fertilizer Management",** a USDA-AFRI grant led by Dave Bullock in the Department of Agricultural and Consumer Economics. This project facilitates data collection and management to help farmers make informed decisions aimed at reducing the environmental impacts of nitrogen fertilizers. Another goal is to improve agricultural research and agribusiness collaborations between the U.S. and Latin America.

- **"Participatory Organic Corn Breeding and Testing Network"** This recent award from the Organic Agriculture Research and Extension Initiative (OREI) to Carmen Ugarte will enable farmers, researchers, and consumers to participate in breeding corn optimized for organic production. In the spirit of "field to table", farmers will help test maize germplasm developed at the University of Illinois and the Mandaamin Institute in Wisconsin, and consumer feedback will guide further improvements.
- **"USDA Producer Education Tool Project"**, USDA Farm Services Agency grant to Jonathan Coppess and the National Coalition for Producer Education. Based on the popular ***farmdoc*** platform, the project develops web-based tools to aid producers make farm-level decisions with regional data input regarding choices offered in the Agricultural Act of 2014.
- **"Center for Advanced Research in Drying"**, a NSF Industry/University Cooperative Research led by Hao Feng and Irfan Ahmad (http://www.dryingresearch.org/). A joint project with the Worcester Polytechnic Institute in Massachusetts and significant industry collaboration, research focuses on efficient and sustainable technologies for drying moist, porous materials such as food and other agricultural products, forestry products, chemicals, textiles, and biopharmaceuticals.
- **"Bio-Conversion of Herbaceous Biomass to Sugars and Biofuels using a Two-Stage Low Severity Pretreatment."** A partnership between Dr. Vijay Singh and the USDA-ARS National Center for Agricultural Utilization Research, this project is developing an integrated bioprocess using advanced yeast strains developed by ARS. This project complements the effort funded by the State of Illinois to build the Integrated Bioproducts Research Laboratory (IBRL). When completed in 2018, the IBRL will provide a uniquely designed space for direct industry-university collaboration for the development of bioproducts from scalable biorefining capacity.

The value of agricultural research and implications for the nation and world.

Agriculture, food, and related industries contributed nearly $100 billion, or nearly 6%, to the U.S. gross domestic product (GDP) in 2015 and employed 11% of Americans (USDA Economic Research Service). On the farm, only 1.4% of the population is able to supply most of our domestic calories, and via exports is a major global contributor to feeding the world. Although agricultural research certainly cannot claim credit for all of this bounty, Figure 2 illustrates through historical increases in U.S. corn yields the compounding benefits from new discoveries and technology innovation, which give birth to new industries and gains in efficiency. Edward East, Hopkin's graduate student, helped produce the first corn hybrids in the 1920s. Continued research at universities and the USDA created the germplasm that companies like Dekalb Genetics and Pioneer HiBred developed into the first commercially successful hybrids (nicknamed "mortgage lifters") in the 1930s. Over the next 50 years, progressively greater efficiencies in hybrid improvement through public-private research partnerships drove ever-higher corn yields. Beginning around 1980, major advances in molecular biology, biotechnology and genome science during each successive decade have helped maintain increases in yields of corn and many other crops and livestock. More recently, multi-scale and high-throughput methods for measuring plant traits in digital formats, named "phenomics" as a play on the word genomics, have become an active area of research that links engineering automation and "big data" science with crop improvement. Finally, genome editing promises yet another leap forward both as a basic research tool and to design crops with improved yields, nutritional qualities, and environmental resiliency.

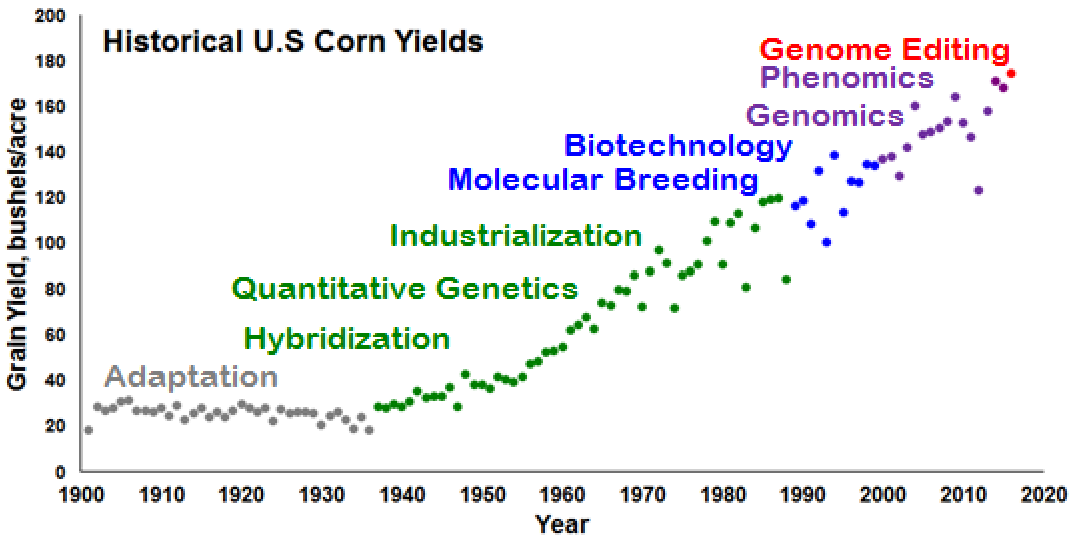

Figure 2: Progressive application of major outcomes from agricultural research that have powered dramatic and continuous increases in U.S. corn yields throughout the past century. U.S. average corn yields from USDA, with data points colored according to the era where that research advance first became a major contributor to yield increases. Similar plots could be drawn for other crops and livestock.

Interestingly, for each of the technology advances indicated in Figure 2, there was a lag period of a decade or more from the initial discovery or research breakthrough to first commercial applications. This delay arises from the substantial risks associated with translating new ideas into successful products. One significant value to agricultural research is to reduce these risks and accelerate commercial adoption. Increasing the pace of innovation is critical to meeting projected greater global demand for food and agricultural products.

The United States is the global leader in agricultural research. U.S. scientists are engaged worldwide in elevating agriculture, through indirect technology diffusion but also direct interactions with international researchers who work at universities, government institutes, the network of Consultative Group of International Agriculture Research (CGIAR) centers, and private foundations. Furthermore, U.S. farmers are the best educated in the world. Continued support for agricultural research will keep America at the forefront of discovery, and bring those discoveries to the farm. We should be vigilant to avoid the "brain drain" experienced by the European Union during the last two decades, where despite an early headstart and its status as an equal scientific rival to the U.S. in biotechnology research during the 1990s, EU governments could not agree on policies to manage this new science to the benefit of their citizens. Unfortunately, their dispute has also slowed agricultural innovation throughout Africa and Asia. China is also now sending signals that it intends to develop a strong bioeconomy, through the purchase of Syngenta by ChemChina and the designation of biotechnology as a strategic emerging industry by the Chinese government.

Figure 2 also emphasizes that investments in agricultural research have long term value, which accrues from the continuous cycle of education, discovery, and application. In strictly economic terms, the effectively linear increase in U.S. corn yields of approximately two bushels per year generates an annual return of more than $600 million dollars at the farmgate, with additional value being generated via processing into food and energy. When other crops and livestock are considered, it is easy to project an annual value from agricultural research in the billions.

I close my remarks by also noting another essential value achieved through agricultural research, but one which it is not easy to estimate in dollars. We have witnessed tremendous changes in the science and technology used in agriculture during the past century, which have occurred during the same period that America transitioned from a majority of the population being engaged in agriculture to now less than 2%. Although society certainly reaps the benefits illustrated by Figure 2 for U.S. corn yields, most experience them only indirectly. Urbanization has unintentionally disconnected much of the populace from the innate desire to know where one's food come from. Research also shows us that some aspects of our highly-industrialized cropping systems, which are often lumped together as "Big Ag", cause environmental damage, and will require new strategies to ensure both economic and environmental sustainability. Because many in society are genuinely interested in how agriculture is practiced and food is produced, agricultural research represents a unique venue through which to engage people with scientists and farmers in the shared goal of a higher quality of life for both humans and planet Earth. One possible path for such future research is to harness the new capabilities in collection and analysis of data captured in an automated manner during farming operations. U.S. agriculture certainly benefits from its diversity of cropping systems and management practices. However, the distributed nature of manually collected data, coupled with the dynamic seasonal variations in climate, have precluded direct empirical comparisons of their productivity and environmental impacts. The "Big Data" revolution that is now upon us represents an opportunity for all farms to become research plots, where again, farmers become scientists, and science is returned to the farm. Research that generates, analyzes, and disseminates these data broadly among the many participants and stakeholders of U.S. agriculture will further improve our collective capacity to "Put Food on the Table".

Thank you for the opportunity to testify today, and I look forward to your questions.