

**REALIZING THE CONSERVATION BENEFITS OF
PRECISION AGRICULTURE**

HEARING
BEFORE THE
SUBCOMMITTEE ON CONSERVATION AND FORESTRY
OF THE
COMMITTEE ON AGRICULTURE
HOUSE OF REPRESENTATIVES
ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

OCTOBER 22, 2019

Serial No. 116-21



Printed for the use of the Committee on Agriculture
agriculture.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE

39-752 PDF

WASHINGTON : 2020

COMMITTEE ON AGRICULTURE

COLLIN C. PETERSON, Minnesota, *Chairman*

DAVID SCOTT, Georgia	K. MICHAEL CONAWAY, Texas, <i>Ranking</i>
JIM COSTA, California	<i>Minority Member</i>
MARCIA L. FUDGE, Ohio	GLENN THOMPSON, Pennsylvania
JAMES P. McGOVERN, Massachusetts	AUSTIN SCOTT, Georgia
FILEMON VELA, Texas	ERIC A. "RICK" CRAWFORD, Arkansas
STACEY E. PLASKETT, Virgin Islands	SCOTT DESJARLAIS, Tennessee
ALMA S. ADAMS, North Carolina	VICKY HARTZLER, Missouri
<i>Vice Chair</i>	DOUG LAMALFA, California
ABIGAIL DAVIS SPANBERGER, Virginia	RODNEY DAVIS, Illinois
JAHANA HAYES, Connecticut	TED S. YOHO, Florida
ANTONIO DELGADO, New York	RICK W. ALLEN, Georgia
TJ COX, California	MIKE BOST, Illinois
ANGIE CRAIG, Minnesota	DAVID ROUZER, North Carolina
ANTHONY BRINDISI, New York	RALPH LEE ABRAHAM, Louisiana
JEFFERSON VAN DREW, New Jersey	TRENT KELLY, Mississippi
JOSH HARDER, California	JAMES COMER, Kentucky
KIM SCHRIER, Washington	ROGER W. MARSHALL, Kansas
CHELLIE PINGREE, Maine	DON BACON, Nebraska
CHERI BUSTOS, Illinois	NEAL P. DUNN, Florida
SEAN PATRICK MALONEY, New York	DUSTY JOHNSON, South Dakota
SALUD O. CARBAJAL, California	JAMES R. BAIRD, Indiana
AL LAWSON, JR., Florida	JIM HAGEDORN, Minnesota
TOM O'HALLERAN, Arizona	
JIMMY PANETTA, California	
ANN KIRKPATRICK, Arizona	
CYNTHIA AXNE, Iowa	

ANNE SIMMONS, *Staff Director*

MATTHEW S. SCHERTZ, *Minority Staff Director*

SUBCOMMITTEE ON CONSERVATION AND FORESTRY

ABIGAIL DAVIS SPANBERGER, Virginia, *Chair*

MARCIA L. FUDGE, Ohio	DOUG LAMALFA, California, <i>Ranking</i>
TOM O'HALLERAN, Arizona	<i>Minority Member</i>
CHELLIE PINGREE, Maine	RICK W. ALLEN, Georgia
CYNTHIA AXNE, Iowa	RALPH LEE ABRAHAM, Louisiana
	TRENT KELLY, Mississippi

FÉLIX MUÑIZ, JR., *Subcommittee Staff Director*

CONTENTS

	Page
Conaway, Hon. K. Michael, a Representative in Congress from Texas, opening statement	28
LaMalfa, Hon. Doug, a Representative in Congress from California, opening statement	3
Prepared statement	3
Spanberger, Hon. Abigail Davis, a Representative in Congress from Virginia, opening statement	1
Prepared statement	2

WITNESSES

Madison, Dustin, Producer and Farm Manager, Engel Family Farms, Louisa, VA	5
Prepared statement	6
Karsten, Ph.D., Heather D., Associate Professor, Crop Production/Ecology, Department of Plant Science, College of Agricultural Sciences, Pennsylvania State University, University Park, PA	9
Prepared statement	10
Supplementary material	43
Cameron, Don J., Vice President and General Manager, Terranova Ranch, Inc.; Owner, Prado Farms, Helm, CA; on behalf of California Farm Bureau Federation	18
Prepared statement	20

REALIZING THE CONSERVATION BENEFITS OF PRECISION AGRICULTURE

TUESDAY, OCTOBER 22, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON CONSERVATION AND FORESTRY,
COMMITTEE ON AGRICULTURE,
Washington, D.C.

The Subcommittee met, pursuant to call, at 2:04 p.m., in Room 1300 of the Longworth House Office Building, Hon. Abigail Davis Spanberger [Chair of the Subcommittee] presiding.

Members present: Representatives Spanberger, O'Halleran, Pingree, Axne, Schrier, LaMalfa, Allen, Abraham, and Conaway (*ex officio*).

Staff present: Prescott Martin III, Félix Muñoz, Jr., Alison Titus, Josh Maxwell, Ricki Schroeder, Patricia Straughn, Dana Sandman, and Jennifer Yezak.

OPENING STATEMENT OF HON. ABIGAIL DAVIS SPANBERGER, A REPRESENTATIVE IN CONGRESS FROM VIRGINIA

The CHAIR. This hearing on the Subcommittee on Conservation and Forestry entitled, *Realizing the Conservation Benefits of Precision Agriculture*, will come to order.

Good afternoon. I would like to welcome everyone to the Conservation and Forestry Subcommittee's hearing on realizing the conservation benefits of precision agriculture. I would like to thank Ranking Member LaMalfa for his engagement on this issue, as well as each Subcommittee Member for taking part in the hearing today. I would like to welcome one of my constituents, Mr. Dustin Madison, from Louisa County, Virginia. Dustin, I am glad that we have your expertise from farming your own land and serving many other farmers in forming our discussion today. Your knowledge from being a technical service provider for NRCS, a certified Virginia resource management planner, and a certified crop advisor will be especially useful. It was a real pleasure to visit Louisa County as part of my 2 day farm tour in August, and it is great to have you here today.

I would also like to welcome our other witnesses, Mr. Don Cameron and Dr. Heather Karsten. Thank you for traveling to Washington, D.C. to share your insight.

As technology within the agriculture industry continues to make leaps and bounds, we are seeing farmers grow more food while more judiciously using inputs such as water and fertilizer. Precision agriculture offers producers opportunities to farm more efficiently and more sustainably. Farmers know that growing condi-

tions can vary significantly, even within the same field, and these factors range from soil type and chemistry to fertility and productivity, to the amount of water in the ground. Precision agriculture makes it possible to calculate how these differences translate into different levels of inputs so that each part of the field is only getting as much as it needs. This means that farmers are saving time, fuel, and money, while increasing their output. It is more efficient and it yields better crops.

Precision technology has applications for animal agriculture as well. It is now possible to monitor feed production, herd health, and energy use on farms to improve efficiency, productivity, and the quality of animal care. And central to our hearing today, precision agriculture enables farmers to enhance production and lower their costs, while at the same time delivering environmental benefits. Site-specific crop management translates into less soil erosion and nutrient run-off. It also improves soil health and water quality, while also providing insight into producers' environmental footprint and creating opportunities for them to adopt practices that enhance both yields and conservation.

Today, I am eager to discuss how farmers are using precision agriculture technologies, what successes they are experiencing, and what barriers are impairing their ability to implement precision ag. And how does this impact their productivity, their competitiveness in the United States and global markets, and their environmental footprint? It is also my hope that today's hearing can serve as a launch pad for us to discuss ways we here in the House of Representatives can help more farmers adopt these tools.

[The prepared statement of Ms. Spanberger follows:]

PREPARED STATEMENT OF HON. ABIGAIL DAVIS SPANBERGER, A REPRESENTATIVE IN
CONGRESS FROM VIRGINIA

Good afternoon. I would like to welcome everyone to this Conservation and Forestry Subcommittee hearing on "Realizing the Conservation Benefits of Precision Agriculture."

I would also like to thank Ranking Member LaMalfa for his engagement on this issue, as well as each Subcommittee Member for taking part in the hearing today.

I want to welcome one of my constituents, Dustin Madison from Louisa County, Virginia. Dustin, I'm glad that we will have your expertise from farming your own land and serving many other farmers informing our discussion today. Your knowledge from being a Technical Service Provider for NRCS, a certified Virginia Resource Management Planner, and a Certified Crop Advisor will be especially useful, I am sure. It was a real pleasure to visit Louisa County as part of my 2 day farm tour in August, and it's great to have you here today.

I would also like to welcome our other witnesses, Mr. Don Cameron and Dr. Heather Karsten. Thank you for traveling to D.C. to share your insight. As technology within the agriculture industry continues to make leaps and bounds, we're seeing farmers grow more food while more judiciously using inputs such as water and fertilizer. Precision agriculture offers producers opportunities to farm more efficiently and more sustainably.

Farmers know that growing conditions can vary significantly, even within the same field. These factors range from soil type and chemistry, to fertility and productivity, to the amount of water in the ground.

Precision agriculture makes it possible to calculate how these differences translate into different levels of inputs—so that each part of the field is getting only as much as it needs.

This means that farmers are saving time, fuel, and money while increasing their output. It's more efficient and it yields better crops. Precision technology has applications for animal agriculture as well. It is now possible to monitor feed production, herd health, and energy use on farms to improve efficiency, productivity, and the quality of animal care.

And central to our hearing today, precision agriculture enables farmers to enhance production and lower their costs, while at the same time delivering environmental benefits.

Site-specific crop management translates into less soil erosion and nutrient runoff. It also improves soil health and water quality, while also providing insight into producers' environmental footprint and creating opportunities for them to adopt practices that enhance both yields and conservation.

Today, I'm eager to discuss how farmers are using precision ag technology—what successes are they experiencing and what barriers are impairing their ability to implement precision ag? And how does this impact their productivity, their competitiveness in U.S. and global markets, and their environmental footprint? It's also my hope that today's hearing can serve as a launch pad for us to discuss ways we here in the House can help more farmers adopt these tools.

With that, I would like to recognize the Ranking Member, the distinguished gentleman from California, Congressman Doug LaMalfa, for 5 minutes.

The CHAIR. And with that, I would like to recognize the Ranking Member, the distinguished gentleman from California, Congressman Doug LaMalfa, for 5 minutes.

**OPENING STATEMENT OF HON. DOUG LAMALFA, A
REPRESENTATIVE IN CONGRESS FROM CALIFORNIA**

Mr. LAMALFA. Thank you, Madam Chair Spanberger, for holding today's hearing, and the way we conduct this Committee. I really appreciate it.

We are here, of course, as you mentioned, to examine the benefits of precision agriculture on conservation, which is indeed one of the many tools we have at our disposal to help improve conservation practices on farms and ranches.

Indeed, rapid advances in technology over the last several years—I would say several decades—has made precision agriculture more important because of the benefits it will provide. Going back to the Dust Bowl era is really when we started learning the importance of this in this country, and the ASCS was formed, Ag Stabilization and Conservation Service. You hear those words, stabilization and conservation, very important as the lessons we learned from the Dust Bowl era and since.

Precision agriculture has increased productivity and in my own experience growing rice with fewer inputs required on our land, water savings, less fertilizer, less pesticides needed. I spent a lot of hours myself on a tractor with a laser-guided leveler making our fields flat and almost perfect to within $\frac{1}{8}$ "', theoretically, on the soil there in order to use less water and keep those weeds from getting away from us, therefore being able to use less pesticides to control that pesky water grass. It has really been important to see that laser technology now morph into GPS, which is even more precise. It actually will take into account the curvature of the Earth. You want level water, you are going to get level water that way in rice. But in so many other ways, these inputs have been helpful in so many aspects of agriculture to bring that precision and be able to make our inputs go farther, and using the things we don't want to have to use much less.

When we talk about the overlap again, if you are able to run your disc, your implement on a much narrower gap and not waste time doing the same acres over and over again, it is better for soil, and it is even easier on the operator to not have to be so on target the whole time, every pass all day, that it is better on the employees.

In a challenging period when farmers face these price pressures for production, price pressures for increased costs of inputs, precision agriculture really helps give you an edge in order to stay profitable and competitive.

There are many benefits we will talk about this afternoon, but we have a chance to hear from people first-hand about this technology. In the 2018 Farm Bill, we also included several provisions to extend broadband so we can bring more broadband to Americans in the most rural areas of the nation. It is important in being able to help utilize this technology and the data that is gathered when we are out there tracking yields. For example, on my rice combine you are able to map out what the yields are doing in a field, and that helps you decide how you want to treat that field the next year with how much fertilizer or other issues you could be tracking as you go. Broadband is important for a lot of different aspects of agriculture. We have more and more of that so we can transfer this data and use it and take the most advantage of it.

The farm bill had EQIP that was able to help with these conservation practices and this precision that we need. And so, I could go on and on about this, but I am a true believer because we use it ourselves and I have seen so many of my neighbors benefit from being able to further track your yields, fertilizer inputs, and all those things that make this technology more and more important as we go forward.

I saw some very impressive technology down in Mr. Panetta's district here on a recent tour that will be very exciting to see that come forward in the future as well.

So with that, I will turn it back to our Chair, and I appreciate the time here today.

The CHAIR. Thank you.

In consultation with the Ranking Member and pursuant to Rule XI(e), I want to make other Members of the Subcommittee aware that Members of the full Committee may join us today, and I thank the Ranking Member of the full Committee for joining us here today.

The chair would request that other Members submit their opening statements for the record so witnesses may begin their testimony, and to ensure there is ample time for questions today.

I would like to welcome our witnesses. Thank you very much for being here today. It is my pleasure and my privilege to welcome Mr. Dustin Madison from Louisa County, Virginia, a constituent of Virginia's 7th Congressional District. Mr. Madison, it is great to have you join us here today. Mr. Madison grew up on his family's crop and cattle farm in Louisa, and now operates 100 acres of his own farmland. He also manages agronomy and conservation initiatives on Engle Family Farms, which raises corn, soybeans, wheat, and other crops on 20,000 acres across the Commonwealth. Mr. Madison is a graduate of Virginia Tech.

Our next witness is Dr. Heather Karsten, Associate Professor within the Department of Plant Science at Pennsylvania State University. Dr. Karsten teaches and conducts research and extension education in agronomy and agroecology. Her interdisciplinary cropping research seeks to develop systems to sustain long-term farm

productivity and profitability while reducing environmental impacts.

And for our final witness, I will yield to my colleague from California for the introduction.

Mr. LAMALFA. Thank you. Thank you again for the opportunity.

As we know, many ranchers and farmers in California have adopted much of this technology, as a lot of it evolves in California. And so, I am pleased to be able to have one of those producers here today.

Mr. Don Cameron, since 1981, has been the Vice President and General Manager of Terranova Ranch in Helm, California, where they currently grow over 25 different crops. Twenty-five. Sometimes it is plenty to do one where I am from, but in addition to his work at Terranova Ranch, Mr. Cameron owns Prado Farms in Fresno County, California. It is an honor to have you here today representing California, along with some of your delegation here.

We have a great panel of witnesses in front of us today, and I am glad to have them travel here all the way to D.C. to spend time with us and help educate all of us, our staffs, and those that are going to see this testimony on TV. Thank you once again, Chair Spanberger, and I yield back.

The CHAIR. We will now proceed to hearing from our witnesses. Each of you will have 5 minutes to present testimony. When the light turns yellow, that indicates there is 1 minute left to complete your testimony.

Mr. Madison, may you please begin when you are ready?

**STATEMENT OF DUSTIN MADISON, PRODUCER AND FARM
MANAGER, ENGEL FAMILY FARMS, LOUISA, VA**

Mr. MADISON. Good afternoon, Chair Spanberger, Ranking Member LaMalfa, and Members of the Subcommittee. I want to thank you all for the opportunity to be here today and talk about this topic that is pretty near and dear to me, as it is part of my everyday life.

Precision and conservation and agriculture really go hand in hand, and it is something that I touch pretty much from sun up to sun down.

I think my time here is best spent telling you that conservation and precision agriculture are really, really big topics, and we could go a long time and not really scratch the surface. I am going to shorten that as much as I can and start with a little background on conservation.

Even in the 1990s, here in Virginia conservation and agriculture were not even in the same conversation. They were two different things. We farmed and then you recycled or clipped the little plastic rings around a six-pack so that you didn't hurt the birds and the fish. Two different worlds. Eventually, we figured out that wasn't a great idea. I could plow a field and it could rain the next day. All my dirt, all my topsoil, all my nutrients would go down a hill into the creek, ending up somewhere in the Chesapeake Bay.

Fast forward to today, we do a lot better. No-till cover crops, things like that are big conservation words, but they are a big part of our lives. That is a really big change. I don't think I can overstate that enough.

Switch over to precision ag. In the 1990s, it really wasn't a thing either. We didn't know we would have the capabilities to do some of the things we can do. We can farm down to 1". Our fertilizer doesn't overlap. We know exactly where we are all the time. Our equipment is so good that we can watch movies on an iPad while we are planting and harvesting. We just have to hit pause to turn around. That is how far we have come.

Now, one of the best parts about the precision ag and the conservation in ag is if you combine the two, we can really make ourselves a lot more profitable, and we can verify that. The precision ag allows us to look at our information after years over, and say, "Hey, we did a better job and we can see it in the bank account." That is the most important thing there is to farming, especially right now. If we can make better decisions and we can not lose money at the end of a year, that is huge. We never would have been able to quantify that without some of the benefits of precision ag, and we couldn't have recognized it without the benefits of conservation.

That is as simple of a message that I can really give anybody is that it is the same as in any business. Put your money where it counts, make good decisions, use all the data you have available to make those decisions, and hit the repeat button.

I have spent a lot of time working with other growers, talking about precision ag, but more talking about conservation in ag. My role as a registered TSP through NRCS has given me the chance to go out and talk to people and see what they are doing now, what they could be doing, and maybe find out why they are not doing anything differently. But again, there are a lot of pieces to that puzzle, but at some point we have to figure it out by being on the ground, talking to them, figuring out what it is we can do. Is it more money? Is it more incentive? Is it just somebody there to hold your hand when you need some help? What is it going to take to do a better job?

I know farmers are willing to step up and do that, not only to help the environment, because things look better when they do, but to keep their businesses going, which is at the end of the day, that is all our main goal.

I want to thank you all again for the chance to be here. This really is an honor. Thanks.

[The prepared statement of Mr. Madison follows:]

PREPARED STATEMENT OF DUSTIN MADISON, PRODUCER AND FARM MANAGER, ENGEL FAMILY FARMS, LOUISA, VA

Good morning, Chair Spanberger, Ranking Member LaMalfa, and Members of the Subcommittee. Thank you for the opportunity to testify on the important topic of precision agriculture in conservation. My name is Dustin Madison, and along with operating 100 acres of my own farmland in Louisa County, Virginia, I manage agronomy and conservation initiatives on Engel Family Farms. We raise corn, soybeans, wheat and other crops on 20,000 acres across the Commonwealth, spread out over 17 counties.

Conservation + Agriculture

To understand the conservation benefits of precision agriculture, I would like to first pull the precision piece out, and just look at the history of conservation and agriculture. Conservation and agriculture have a different relationship than they did 40, 30, or even 10 years ago. My impression of "conservation" in the 1990s was that it was all about rainbows and unicorns living in lush green fields, contrasting

the *industrial* world. We recycled aluminum and cut the plastic rings when you bought a six-pack to protect the fish and birds, but agriculture didn't really fit into the picture. Farm work was always messy; too muddy or too dusty. It came with the territory.

Day after fall day, I would till fields until 9 or 10 at night, then go home and eat the dinner my mom had left in the refrigerator. If it rained the next day, all that nutrient-rich top soil washed down the hill, into a creek, and eventually into the Chesapeake Bay. That's just the way things were. We certainly didn't want to see our hard work and money get washed out of the fields that we were betting our whole year's income on. We did our work the same way it had always been done and essentially rolled the dice. Conservation practices address a lot of these issues now, but back then, we just didn't put it together. Conservation was one thing and agriculture was another.

Fast forward into the early 21st Century, and we have the early adopters of precision agriculture. Using computers onboard our tractors, harvesters and other equipment, we found a reliable method of collecting millions of data points every time we crossed a field. As these layers of data accumulated, it became easier to pick out trends and patterns in our fields that we could only get before from memory, gut feelings and countless notes scribbled down and lost amongst the "file cabinet" that was the dashboard of our pickup trucks.

Now, what we call conservation practices are some of the most profitable management decisions we can make, in a large part because of precision ag. What's even better is that we can further utilize the components of precision ag at year's end to measure and verify the financial impacts of those decisions.

For example, we can easily look at trends of poor yields and trace the causes back to poor soil types that leach fertilizers rather than hold them in a root zone for a productive crop. Then, we can identify the specific areas that aren't working and stop farming them. A field may go from 25 acres down to 23 acres using this method, but overall farm profitability can often rise in these situations.

The message here was very simple: Don't invest your input dollars into a part of your business that won't produce a financial return. Make a better decision, save that money, and use it somewhere that creates value for your business. Conservation practices are those better decisions, and precision ag is the tool that allows you to quantify them.

Because of a pretty rudimentary function of precision ag, we in agriculture made a historically complex problem into a straightforward business decision, while also taking away many of the variables that easily cloud judgment. I know of countless examples of situations like this, all supporting the notion that conservation in ag, through precision ag as a foundation, can create positive environmental change, while at the same time increasing farm profitability (which is, selfishly, of more benefit to producers everywhere).

There are better people than me for describing the inner workings of computers, data processing and in-field equipment integration, which are the backbone of precision agriculture. But as a farmer, whose livelihood depends on producing commodities, I can talk all day about the importance of finding ways to make better, profitable decisions so we can remain in business. If there is a way to do what we do better for the environment and, in turn, for our bank accounts, farmers will respond. We don't have the option not to.

Barriers

For all the benefits to integrating precision ag onto every farm, there are significant barriers to entry for many producers.

1. Technology is expensive. We have reached a time when some ag technology has been around long enough that there are more economical ways to achieve precision goals, but more economical doesn't necessarily mean affordable for everyone. The larger farmers can buy in easier simply because of scale. Smaller farmers are more limited.
2. I could show you all kinds of cool technology that can provide valuable data and perform actions that really add to the bottom line. However, tech can fail at any moment for 1,000 reasons: No Internet connectivity, bugs in the software, satellite interference, human frustration or even problems off the farm: If a service provider's software is down, we can do everything right and still have problems with our data.
3. Farmers need to understand the benefits of conservation through precision agriculture, and outreach and communication of available resources are needed to have more widespread adoption. This dialogue between farmers and local technical experts needs to be ongoing so producers can adopt greater levels

of conservation and be aware of emerging technologies and solutions. Most years, local Soil and Water Conservation Districts and the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) are not able to meet the demand from farmers for these practices because of either a lack of enough funding, not having enough technical staff to certify the practice or review the purchase of equipment, or not having enough technical staff to help farmers better understand the benefits of utilizing these practices or equipment.

Solutions

I do think the continued efforts by our Soil and Water Conservation District and NRCS staff have helped us tremendously in getting to where we are today in our ag conservation efforts in a relatively short period of time. However, going any further will take continued work, as well as recognition that old methods of communicating and incentivizing our farmers may need updating.

1. The average age of an American farmer is 58 years old. Most of those farmers learned about agriculture from the generation before them and will probably teach the next generation down. The people on the higher end of the age spectrum didn't get into conservation work too heavily, and they certainly didn't get into precision ag. So, while they are passing down years of practical experience and intuition, there is a large group of beginning farmers who will have to do all the heavy lifting in adopting these parts of the industry. Education and outreach focusing on farmers *under* the average age will help close that gap.
2. We need to make sure financial incentives are there for farmers who put conservation practices in place, especially those who are putting precision ag to work. State and Federal cost-share dollars mean more than most can imagine when making the large up-front purchases required to make precision ag work. As mentioned before, the overarching value of precision ag is that it provides a data-driven, informational foundation that so many conservation practices can be built upon. Especially as future farmers are expected to be better financial managers, they will be more receptive to tools that can affect their profitability.
3. We need to remember that partnerships are integral in making something as big as conservation in agriculture happen when there are so many independent stakeholders. I've participated in grants from NGOs that were able to get significant work done in the Chesapeake Bay Watershed. I've received active Environmental Quality Incentives Program (EQIP) contracts through NRCS. But, most interestingly to me, is that NRCS already has a program that combines Federal incentives administered through NRCS with private conservation planning and installation. Private individuals can become Technical Service Providers (TSPs) for NRCS and take some of the workload off of existing staff on an as-needed basis. This is a highly under-utilized program that receives little attention from the agency or farmers. Most on both sides don't even know it exists. I know this because I have been one of only two registered TSPs in Virginia for nearly 5 years. I could have an impact on both precision ag use and conservation planning, yet I have been asked to write a total of **three** conservation plans statewide. The spirit of this program is exactly what gets things done on the ground: Federal help for farmers, managed through local offices and assisted by qualified private service providers when NRCS staff is overloaded with work.

Farming has evolved a great deal from both a conservation and precision agriculture perspective in just the last 30 years, and will continue to do so, especially here in the Chesapeake Bay Watershed, where we symbolize so much on a national scale. If we as producers continue to be innovative and earn the support from the non-farming community that we so badly need, there is no limit to what we can accomplish in the years to come.

I appreciate the invitation to speak before the Subcommittee this morning on this important topic and look forward to answering any questions you might have.

The CHAIR. Thank you very much, Mr. Madison. We appreciate your comments.

Dr. Karsten, you may begin when you are ready.

STATEMENT OF HEATHER D. KARSTEN, Ph.D., ASSOCIATE PROFESSOR, CROP PRODUCTION/ECOLOGY, DEPARTMENT OF PLANT SCIENCE, COLLEGE OF AGRICULTURAL SCIENCES, PENNSYLVANIA STATE UNIVERSITY, UNIVERSITY PARK, PA

Dr. KARSTEN. Thank you, Chair Spanberger, Ranking Member LaMalfa, and distinguished Members of the Committee for this opportunity to discuss the conservation benefits of precision agriculture, which are significant.

Precision agriculture technologies enable farmers to understand and manage the spatial variability on their farms and better respond to changes during the season. These tools can help farmers be more cost-effective and apply inputs and management, reduce environmental impacts of agriculture, and manage for resilience and ecosystem services.

For instance, with fine resolution knowledge about their fields, farmers can avoid over-applying or applying inputs where it would not be cost-effective, such as fertilizers, pesticides, seeds, irrigation. This can avoid loss of inputs to the environment, reduction of water resources, or in the case of pesticides, the loss of biodiversity and the risk of selecting for pest resistance to pesticides.

Precision agricultural technologies can also help farmers identify zones or subfields that could be more profitable with different management. That can also provide conservation benefits. For instance, in zones that are not profitable or low-profit, farmers might decide to plant different crops that are better suited and more profitable, or adopt conservation practices that can reduce erosion, build soil health, and be more resilient to climate change. There are zones that may be more vulnerable to extreme weather and may be better suited for conservation or set-aside plantings. And when they are assisted with decision support tools and decision support systems that include ecosystem, agroecosystem, computer simulation models, land managers can also evaluate the impact of possible management changes. Decision support systems can help them identify practices that best meet their goals, whether they include profitability, resilience to stress, long-term productivity, and environmental stewardship.

The greatest barriers of farmer adoption, from what we understand, are the costs of capital investments needed to adopt precision technologies, the technical expertise needed, and the perceived risks of adoption. Land-grants are ideally suited to address these adoption barriers. With our mission of education, research, and extension, education land-grants can help farmers of all sizes benefit from precision technologies. We are, and we can do more, to teach students to understand and benefit from the site-specific knowledge and precision ag tools to enhance their farm profitability and environmental benefits. Our graduates can contribute to developing these technologies and assisting others with adoption.

Through research, we develop tools that can improve access to fine resolution information and work with farmers to provide more reliable recommendations. We can increase access with tools that are low-cost, free online or open access or open source, and we can improve our understanding and the predictions of how agroecosystems respond to management changes and extreme

weather so that we can better identify which crops, soils, pests, and water management practices are most resilient, profitable, and environmentally friendly.

And finally, through extension, we can help farmers adopt precision agricultural technology and evaluate the tools on their farms. Through that boots-on-the-ground approach, extension can assist growers and others in the agricultural community, including folks in our assistance agencies, consultants, and input providers, to help benefit farmers and conservation goals and long-term sustainable productivity.

Thank you. I look forward to taking your questions.

[The prepared statement of Dr. Karsten follows:]

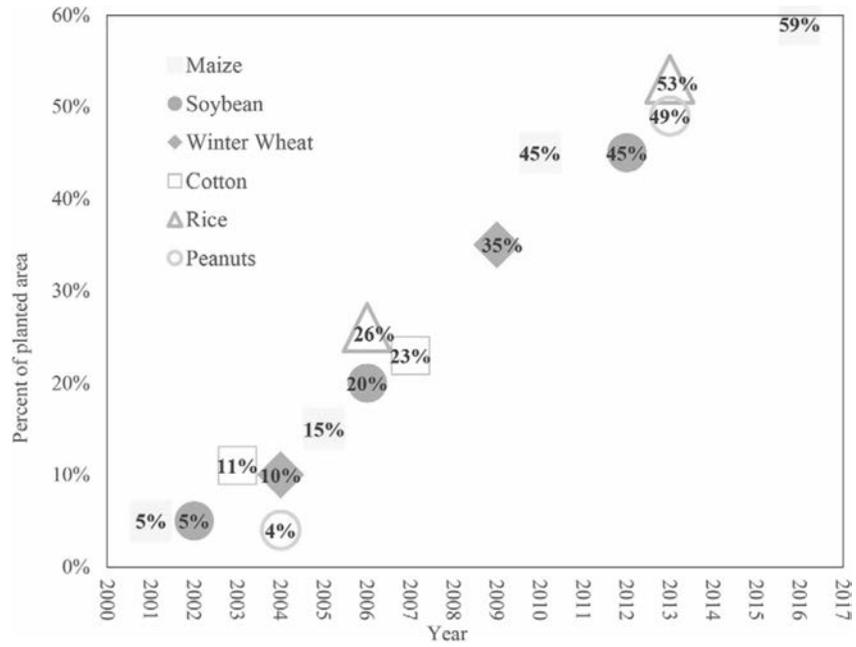
PREPARED STATEMENT OF HEATHER D. KARSTEN, PH.D., ASSOCIATE PROFESSOR, CROP PRODUCTION/ECOLOGY, DEPARTMENT OF PLANT SCIENCE, COLLEGE OF AGRICULTURAL SCIENCES, PENNSYLVANIA STATE UNIVERSITY, UNIVERSITY PARK, PA*

Chair Spanberger and distinguished Members of the Committee, thank you for this opportunity to discuss the conservation benefits of precision agriculture, some examples of precision agriculture, barriers to adoption and the role of the land-grant universities. Precision agriculture technologies are and their potential applications for conservation benefits are diverse and significant. Precision agriculture technologies utilize spatial and temporal agroecosystem and hydrologic data in geographic information systems (GIS) software that can be linked to automate equipment navigation of agricultural operations such as planting and spraying operations via robotic technologies. In addition, real-time data from sensing technologies such as in-field sensors, remote sensing or thermal imaging can be integrated with the GIS data and historical management data in decision support tools (DST) and decision support systems (DSS) (Drohan, *et al.*, 2019). Agroecological and hydrologic computer simulation models are of utilized in decision support systems along with other factors such as weather forecasts and/or economic data to provide farmers and land managers with site-specific management options that can result in reduced environmental impact and economic costs of agricultural activities. For instance, integrating maps of soil characteristics such as fertility, slope and drainage; crop yields, and pest infestations along with weather forecasts can enable managers identify zones for specific application rates of seeds, nutrients, pesticides and irrigation water at the optimal time with variable rate technologies (VRT). Similarly, livestock managers can utilize precision feeding to develop nutritionally balanced cost-effective rations that meet the metabolic needs of livestock at various life stages without excess nutrients.

Adoption Barriers

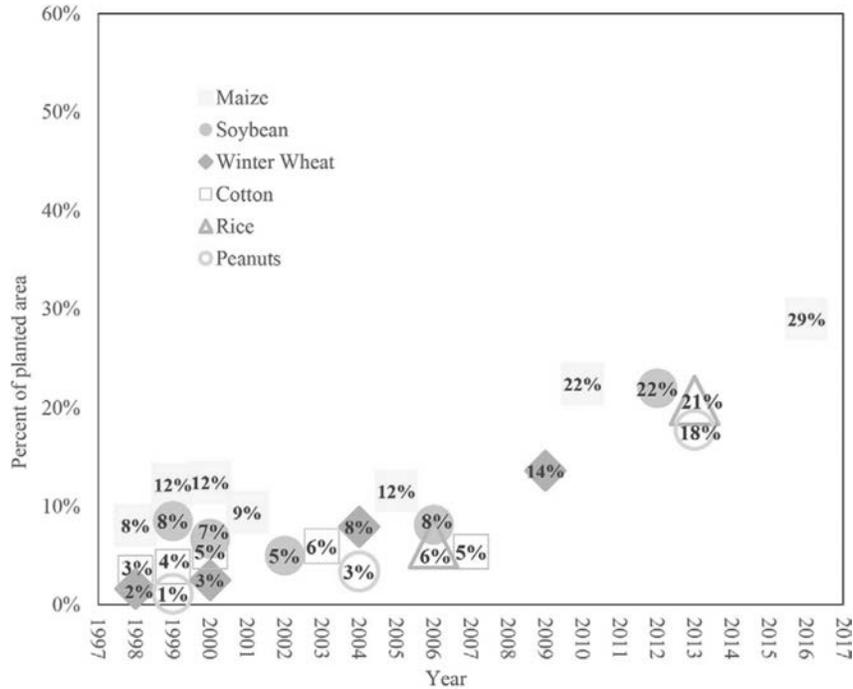
A recent analysis of multiple U.S. survey data on the adoption precision agriculture since 2000, suggested some rapid adoption as well as barriers to adoption. Adoption of global navigation satellite systems (GNSS) with auto guidance and technologies such as sprayer control and planter row or section automatic shutoffs has been relatively rapid for agronomic crops (see *Figure 3* from Lowenberg-DeBoer and Erickson, 2019), while adoption of variable rate technology (VRT) has been relatively slow and “rarely exceeds 20% of farms” (see *Fig. 4* from Lowenberg-DeBoer and Erickson, 2019). The study’s authors summarized three hypotheses for the slow rate of adoption that were frequently described in the surveys cited: i. the cost of VRT was too high, ii. “more reliable VRT decision rules” were needed, particularly for nitrogen, and iii. farmers weren’t convinced VRT would increase their profits (Lowenberg-DeBoer and Erickson, 2019).

* **Editor’s note:** Dr. Karsten submitted an updated version of her statement. due to the number of changes it has been incorporated as *Supplementary Material*, and is located on p. 43.

Fig. 3.

Planted area by crop in the United States where Global Navigation Satellite Systems (GNSS) auto guidance was used, 2000 to 2016.

Fig. 4.



Planted area by crop in the United States where variable rate technology (VRT) was used for any purpose, 1998 to 2016.

Figures 3 and 4 from Lowenberg-DeBoer J. and B. Erickson. 2019. *Setting the Record Straight on Precision Agriculture Adoption*. AGRONOMY JOURNAL 2019 111: 1535–1551, doi:10.2134/agronj2018.08.0535.

Additional adoption barriers that others describe include the need for and technical expertise needed to install and operate precision technologies, and the fact that new equipment is needed to be compatible with the new technologies, as well as additional factors that are summarized and shown below in *Table 1* from Wolfe and Richard (2017).

Table 1—Overview of barriers to the adoption of pro-environmental technological innovations (general and agriculture specific) based on literature review (from Long, *et al.* [31]. Sources are listed in [31] and not repeated here.

Barrier	Sources
Economic	<ul style="list-style-type: none"> High initial investments Poor access to capital Hidden costs Competing financial priorities Long pay-back periods (ROI) Switching costs/existence of installed base High implementation costs (actual and perceived) Uncertain returns and results Temporal asymmetry between costs and benefits Over discounting the future
	<p>(Bogdanski, 2012; Brunke, <i>et al.</i>, 2014; Cullen, <i>et al.</i>, 2013; del Río Gonzalez, 2005; Faber and Hoppe, 2013; Hoffman and Henn, 2008; Luken and Van Rompaey, 2008; Luthra, <i>et al.</i>, 2014; McCarthy, <i>et al.</i>, 2011; Montalvo, 2008)</p>

Table 1—Overview of barriers to the adoption of pro-environmental technological innovations (general and agriculture specific) based on literature review (from Long, *et al.* [31]. Sources are listed in [31] and not repeated here.—Continued

Barrier		Sources
Institutional/regulatory	Low institutional support Use of overly scientific language (Jargon) Farmer's knowledge not considered in R&D Lack of regulatory framework Prohibitively prescriptive standards	(Bogdanski, 2012; Eidt, <i>et al.</i> , 2012; Luthra, <i>et al.</i> , 2014; Montalvo, 2008)
Behavioral/psychological	Lack of management support/awareness Conflict with traditional methods Overly complex technologies Results/effects of technology difficult to observe Farmer's beliefs and opinions Low trust of advisers or consultants/lack of acceptance Irrational behavior Negative presumed assumptions	(Brunke, <i>et al.</i> , 2014; Eidt, <i>et al.</i> , 2012; Hoffman and Henn, 2008; Johnson, 2010; Ratten and Ratten, 2007; Sneddon, <i>et al.</i> , 2011 ; Vishwanath, 2009; Wheeler, 2008)
Organizational	Lack required competencies/skills Poor readiness Poor information Inability to assess technologies Overly short-term/perverse rewards Organizational inertia/habitual routines	(Brunke, <i>et al.</i> , 2014; Faber and Hoppe, 2013; Johnson, 2010; Luken and Van Rompaey, 2008; Luthra, <i>et al.</i> , 2014; Montalvo, 2008)
Consumers/market	Poor information Lack market attractiveness/do not align to preferences Uncertainty Consumers/farmers level of motivation Market uncertainty	(Bogdanski, 2012; Bohnsack, <i>et al.</i> , 2014; Brunke, <i>et al.</i> , 2014; del Río Gonzalez, 2005; Johnson, 2010; Luthra, <i>et al.</i> , 2014)
Social	Social/peer pressures	(Montalvo, 2008)

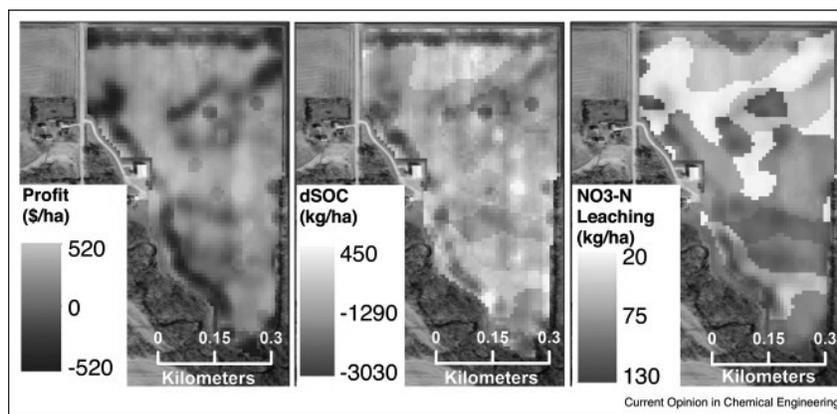
For farmers with limited capital facing small profit margins, the capital investment required for new precision agriculture technologies and the technical expertise required can be significant barriers. Land-grant university researchers and educators such as my colleagues at Penn State are currently working with farmers, the national laboratories and government agencies (ex. NRCS), as well as private-sector partners to develop low cost new technologies and open-source or free software and decision support tools and systems that can be operated on smartphones or personnel computers. Land grants are also well-positioned to conduct objective, trustworthy assessments of precision technologies, while training students, educators and the workforce to develop, improve and assist in the use of precision technologies.

Decision support systems can empower farmers and producers to fine-tune their management practices when coupled with economic incentive policies that promote adoption (Drohan, *et al.*, 2019). Support for on-farm assessment and peer-to-peer learning also appear facilitate adoption of precision conservation technologies. A final report from a Penn State interdisciplinary research and extension project provides an example of what DSS can provide. "There is no one production practice that will make or break a herd's profitability Combining financial metrics with decision-making on cropping and feeding practices is still a challenge for both producers and consultants. . . . The bottleneck is how cropping strategies and animal performance influence the whole farm system and the impact to the bottom line. Unless nutritionists and crop consultants work with financials on a routine basis, it is unlikely they will embrace this aspect when working with their clientele." (Ishler, *et al.*, 2019).

Some examples of precision conservation technologies and DSS that offer promise of adoption are briefly described. Decision support systems (DSS) that produce farm profit maps can enable farmers and land managers to identify opportunities to increase their profits while reducing their environmental impact. Agroecosystem DSS can identify field zones that are consistently low profit or unprofitable enabling land-managers to consider alternative managements. Low profit or very unprofitable zones also are often zones of significant soil and/or nutrient losses associated with

soil and landscape factors (Delgado and Bausch, 2005; Muth, 2014) as illustrated in *Figure 1* from Wolfe and Richard, 2017 that may also make them particularly vulnerable to extreme weather events such as drought or flooding. For instance, a 2017 NRCS funded study of over 200,000 acres from nearly 3800 fields on 136 farms in a dozen states found that (a) more than 90% of fields included zones that were losing money due to some combination of risks, and (b) over 50% of the unprofitable acres were also acres with substantial environmental concerns (Wolfe and Richard, 2017).

Figure 1



Subfield economic analysis demonstrates high variability in profitability, with a significant fraction of currently farmed acres highly unprofitable for annual crops. Left panel: profit in $\$ \text{ha}^{-1}$; center panel: change in Soil Organic Carbon in kg ha^{-1} , and right panel, nitrate ($\text{NO}_3\text{-N}$) leaching in kg ha^{-1} .

Figure 1 from Wolfe, M.L. and T.L. Richard. 2017. *21st Century Engineering for On-Farm Food-Energy-Water Systems*. CURRENT OPINION IN CHEMICAL ENGINEERING <https://doi.org/10.1016/j.coche.2017.10.005>.

Decision support tools that integrate landscape characteristics, with crop management history and yields agroecosystem models and economic analyses and sensor data can help farmers to identify practices for low profit zones to reduce their production costs and/or increase their cropping system resilience (*Fig. 2*. Wolfe and Richard, 2017).

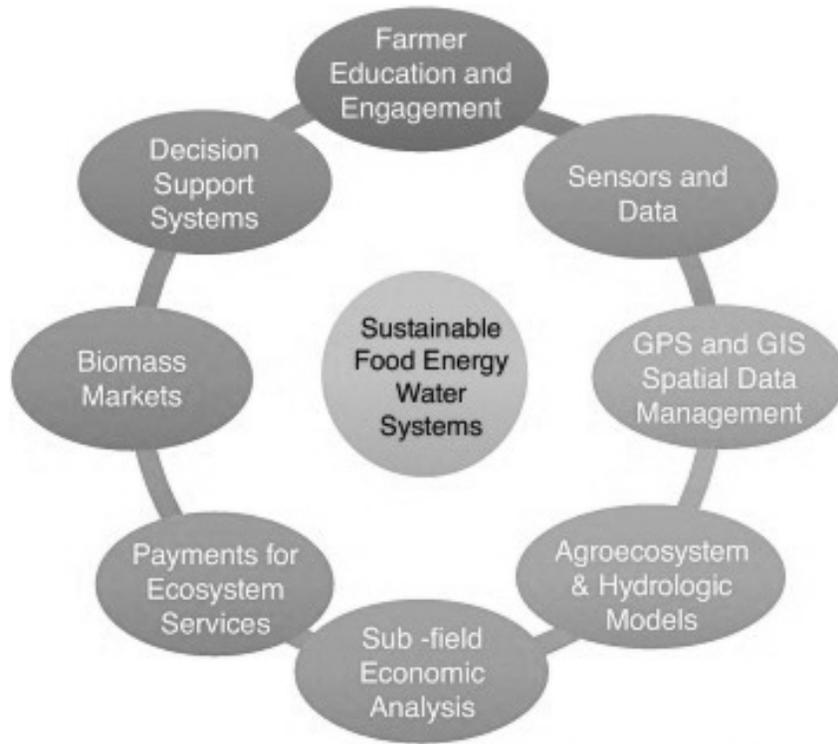
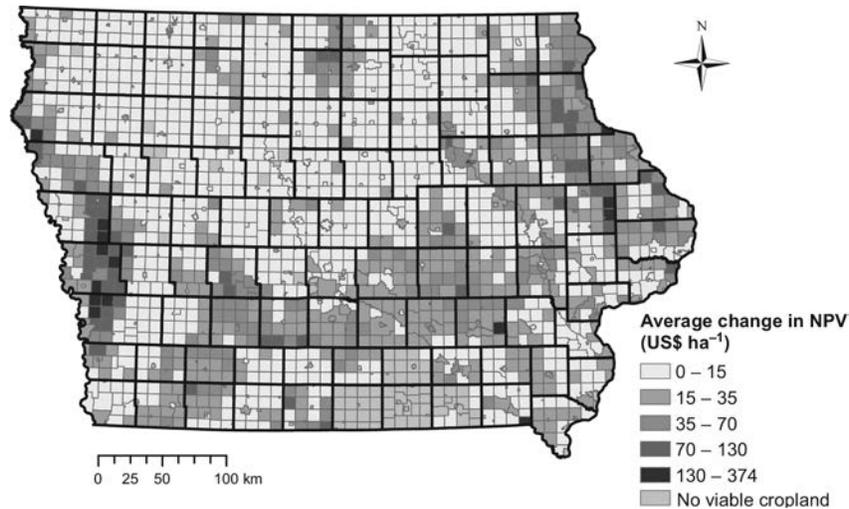
Figure 2**Current Opinion in Chemical Engineering**

Figure 2 from Wolfe and Richard, 2017. Sustainable food-energy-water systems are enabled by an expanded precision agriculture toolset that includes economic analysis, payments for ecosystem services, and biomass markets, all managed through decision support systems that go beyond inputs and single crop management to innovative cropping system and landscape design.

Alternative management scenarios may include reducing fertilizer inputs and adopting conservation farming practices (Delgado and Bausch, 2005, Muth, 2014, Capmourteres, *et al.*, 2018). In zones where annual cropping is unprofitable, the establishment of perennial plants for bioenergy offers a viable economic alternative (Wolfe and Richard, 2017) such as shown below in *Figure 6* from Brandes, *et al.*, 2018.

Fig. 6



Average annualized changes in net present value (Δ NPV) when economically under-performing cropland is converted from corn/soybean to switchgrass. Values (in U.S.\$ ha⁻¹) are calculated by dividing the sum of annualized Δ NPV by the total corn/soybean cropland area per township. Gray areas represent townships without any cropland economically viable in switchgrass. The results assume USDA projected (medium) grain prices, medium switchgrass price, medium switchgrass yield, and that all land is owned by the farm operator.

Figure 6 from Brandes, E., A., Plastina, and E. Heaton. 2018. *Where can switchgrass production be more profitable than corn and soybean? An integrated, sub-field assessment in Iowa, USA*. GLOBAL CHANGE BIOLOGY BIOENERGY. 10, 473–488, doi: 10.1111/gcbb.12516.

Planting perennials (Capmourteres, *et al.*, 2018) and removing zones from production can also provide multiple conservation benefits for a relatively low cost. In Iowa, compared to similar watersheds that were 100% row-cropped, planting only 10% of a corn-soybean field to prairie strips reduced sediment loss by 95%, phosphorus and nitrogen losses by 90% and 85%, while also providing habitat for biodiversity, such as grassland birds and pollinators (Liebman and Schulte, 2015).

Decision support systems (DSS) such as CropSyst (Stockle, *et al.*, 2014) that integrate agroecosystem and hydrological models or climate projections have also been employed to evaluate various management scenarios such as nutrient management or projected climate change impacts and mitigation approaches. Land-grants researchers working with USDA ARS, other national laboratories, and “big-data” have developed multiple DST and DSS to provide growers with information to strategically reduce soil phosphorus and comply with nutrient regulations (Drohan, *et al.*, 2019); and to reduce production costs, pesticide applications, and crop damage from insect pests and disease infestation through free online real-time pest monitoring websites. Some examples of these free online precision technologies and additional precision DST and DSS that were developed or are under development at Penn State are described below.

In conclusion, the strength of land-grants and Penn State is in our ability to bring together diverse faculty and extension educators to work with farmers, USDA partners, national laboratories, and the private-sector. With evidence of multiple opportunities for precision agriculture and conservation technologies to provide environmental and economic benefits, we are advancing the development, application, and educational activities to support farmers and land managers in the conservation of our agricultural and natural resources.

A brief description of some additional precision agriculture technologies that were developed or are under development at Penn State are described below.

- PestWatch is a long-term monitoring program developed at Penn State that has expanded from 200+ stations in the East Coast, to 700+ stations nationwide (mostly MS river and east). PestWatch provides guidance for individual producers on the extent and location of various corn pests in the agricultural regions of the eastern United States. The unique use of climate and weather data within PestWatch has led to additional tools for battling brown-marmorated stinkbugs, slugs, and the newly critical insect pest, Spotted Lantern Fly. The core tool is located at: <http://www.pestwatch.psu.edu/>.
- Wheat Fusarium Headblight is the leading plant pathogen of wheat in the United States and abroad. Penn State, along with collaborators at Kansas State and across the Wheat Belt, has developed the Wheat Fusarium Head Blight Prediction Center to provide farmers with actionable information on this crop pathogen. The Prediction Center, and its associated map tool, has been in continuous use and supported by the USDA Wheat and Barley Scab initiative for more than 19 years. This tool provides daily guidance for farmers across the entire U.S. Wheat growing region. The tool is located at: <http://www.wheatscab.psu.edu/>.
- Reducing the risk of crop damage by using drones, to monitor air temperatures on nights when there is frost and sending commands to ground robots with heaters mounted on them so growers can target only those areas most at risk are protected, while minimizing energy use.
- Precision, automated irrigation systems (drip irrigation) for tree fruit and vegetable crops that operate on soil moisture sensors and IoT (internet of things) system. The use of precision and automated irrigation systems can maximum the water use efficiency (apply water at right time and right amount), reduce the impact to the environment caused by the nutrient leaking, and save energy and costs.

Predictive Models

- Every winter, 30–40% of managed honey bee colonies in the U.S. die. This is an enormous economic cost to beekeepers, and threatens our food security since 75% of our major food crops benefit from the pollination services of honey bees and other insects. Using data provided by Pennsylvania beekeepers, a team at Penn State and the USDA–ARS has developed models which can predict winter survival rates with 70% accuracy. These complex models integrate data on climate, landscape quality, and beekeeper management practices. We have developed an online portal, called Beescape, which allows individuals to evaluate the quality of their landscapes for supporting bee health. We are current integrating our predictive models into Beescape so that beekeepers can understand the risk to their honey bees in their locations, and take steps to improve bee survival. Beescape can easily be adapted to provide information on other measures of honey bee and wild bee health, including honey production and biodiversity. This program is funded by USDA NIFA and the Foundation for Food and Agricultural Research.
- In soybeans, we have been working from an extensive dataset (ten states, 3 years, just under 5,400 responses) to determine under what conditions foliar fungicides would be warranted. We have built a global models for (1) management factors, and (2) management in combination with environmental and physiological parameters, all with the goal to understand under which environmental domains might a foliar fungicide show a positive weight (*i.e.*, influence positively the observed yield).

Remote Sensing and Decision Support Technologies

- We are actively engaged in applied research to use a combination of sUAS-based (drone-based) sensors, including multispectral cameras and LiDAR sensors in both airborne and terrestrial modes, to develop, test, and apply new techniques to measure forest ecosystem attributes at scales ranging from individual trees to forest stands. We combine emerging low-cost reality capture sensors with a seamless user interface, through custom software applications, to foster automation in the forest industry. We aim to transform the current rudimentary and labor-intensive mensuration methodology employed by foresters through the what we've named the "RealForests" system. RealForests fuses low-cost remote sensing hardware and intuitive software design to allow for rapid data collection of key forest attributes for forest appraisal and to support management decisions. Easy data collection integrated into existing field procedures is critical to market entry. Existing algorithms have allowed our team to locate individual tree objects and estimate critical measurements. RealForests will

allow the user to add information, such as species identification, that can be linked to objects in the 3D model of the forest created by the system.

References

- Brandes, E. A., Plastina, and E. Heaton. 2018. *Where can switchgrass production be more profitable than corn and soybean? An integrated, sub-field assessment in Iowa, USA*. GLOBAL CHANGE BIOLOGY BIOENERGY. 10, 473–488, doi:10.1111/gcbb.12516.
- Capmourteres, V., J. Adams, A. Berg, E. Fraser, C. Swanton, and M. Anand. 2018. *Precision conservation meets precision agriculture: A case study from southern Ontario*. AGRICULTURAL SYSTEMS. 167: 176–185. <https://doi.org/10.1016/j.agsy.2018.09.011>.
- Delgado, J.A. and W.C. Bausch. 2005. *Potential use of precision conservation techniques to reduce nitrate leaching in irrigated crops*. JOURNAL OF SOIL AND WATER CONSERVATION. 60(6): 379–387.
- Drohan, P., M. Bechmann, A. Buda, F. Djodjic, D. Doody, J.M. Duncan, A. Iho, P. Jordan, P.J. Kleinman, R. McDowell, P. Mellander, L.A. Thomas, and P.J.A. Withers, et al. 2019. *A global perspective on phosphorus management decision support in agriculture: Lessons learned and future directions*. JOURNAL OF ENVIRONMENTAL QUALITY. 48: 1218–1233. doi:10.2134/jeq2019.03.0107.
- Ishler, V., R. Goodling, T. Beck. 2019. *The Impact of Corn Silage Harvesting and Feeding Decisions on Income Over Feed Costs*. Part of a Final Research and Extension Education report that was funded by NESARE USDA NIFA. April 11, 2019.
- Liebman, M. and Schulte, L.A., 2015. *Enhancing agroecosystem performance and resilience through increased diversification of landscapes and cropping systems*. ELEM. SCI. ANTH., 3, p. 000041. DOI: <http://doi.org/10.12952/journal.elementa.000041>.
- Lowenberg-DeBoer J. and B. Erickson. 2019. *Setting the Record Straight on Precision Agriculture Adoption*. AGRONOMY JOURNAL 2019 111: 1535–1551, doi:10.2134/agronj2018.08.0535.
- Muth, D. 2014. *Profitability versus environmental performance: Are they competing?* JOURNAL OF SOIL AND WATER CONSERVATION. 69(6). 203A–206A. doi: 10.2489/jswc.69.203A.
- Stockle, C.O., A.R. Kemarian, R.L. Nelson, J.C. Adam, R. Sommer, and B. Carlson. 2014. *CropSyst model evolution: From field to regional to global scales and from research to decision support systems*. ENVIRONMENTAL MODELLING & SOFTWARE. <http://dx.doi.org/10.1016/j.envsoft.2014.09.006>.
- Wolfe, M.L. and T.L. Richard. 2017. *21st Century Engineering for On-Farm Food-Energy-Water Systems*. CURRENT OPINION IN CHEMICAL ENGINEERING. <https://doi.org/10.1016/j.coche.2017.10.005>.

The CHAIR. Thank you.

Mr. Cameron, you may proceed when you are ready.

STATEMENT OF DON J. CAMERON, VICE PRESIDENT AND GENERAL MANAGER, TERRANOVA RANCH, INC.; OWNER, PRADO FARMS, HELM, CA; ON BEHALF OF CALIFORNIA FARM BUREAU FEDERATION

Mr. CAMERON. Thank you, Chair Spanberger, Ranking Member LaMalfa, and Members of the Subcommittee for the opportunity to testify today on behalf of the California Farm Bureau Federation. I am Don Cameron, Vice President and General Manager for Terranova Ranch in Helm, California, which is in the central San Joaquin Valley. I also serve as President for the California State Board of Food and Agriculture.

The California Farm Bureau represents nearly 36,000 members across 53 counties, contributing to the largest ag economy of any state in the nation. Our farmers and ranchers provide food, fiber, and feed for our local communities, the nation, and across the globe.

At Terranova, as you heard, we produce about 25 different crops on 7,000 acres. Some of them include processing tomatoes, peppers, onions, carrots, almonds, pistachios, walnuts, and a longer list that I won't get into. But our diversified farming practices encourage our biological systems to be productive, beneficial, and diverse. Our on-farm practices include building infrastructure to implement on-farm groundwater recharge, installation of pressurized irrigation systems, installation of solar generation systems, and irrigation technologies for energy efficiency, using practices that help maintain a diverse wildlife habitat, and upgrading our farm equipment with cleaner engines for better air quality.

I wish to raise several considerations for the Subcommittee to be aware of as you consider Federal policy relative to conservation, precision agriculture, and water certainty.

First, it is essential that farms have flexibility to try new ways of farming that might improve practices. The practices, while we have great success in some areas, we have also had failures in others. The adoption of processes can be extremely costly and time consuming. Practices that work well for our operation do not nec-

essarily work well for the neighboring operation or for another farming region.

Second, farmers and ranchers are at the ready to adopt new technologies and practices, but it is critical that they are readily available, scientifically trialed, and affordable to the operation and the crops being grown. Pressurized irrigation systems are generally more costly to install and operate than furrow irrigation techniques, and may not be economically feasible for every crop or operation. Additionally, these systems may rely on a new skillset and additional investments in training that need to be made.

Third, we must also be cognizant of the unintended consequences that can exist with resource decision-making. Industrial pumps, motors, on-demand pressurized drips, lines, tailwater recovery, recirculation of water for the reuse can result in increased energy demand, and a time shift on when energy demand occurs. While precision agriculture can assist producers while reducing their consumptive water use, the unintended consequences can be less water returning to the groundwater below the crop.

In light of these considerations offered above, we also offer the following recommendations to the Subcommittee for consideration.

First, the Environmental Quality Incentives Program is by far the most utilized program in California, assisting producers achieving greater conservation goals. We particularly thank you for including funding for the air quality incentives, which have been incredibly important to farmers in California who face strict air quality standards. The RCPP has also allowed infrastructure conveyance to be extended in many areas with groundwater return projects, like ourselves. It is essential that NRCS technical assistance funding is commensurate to voluntary financial assistant levels, assisting producers with their adoption.

Second, it is important to realize that there is no one size that fits all for precision ag practices. Each field crop and operation will have different conservation and economic needs to factor in, and we must be cautious in making value judgments and using our motivation and resources to identify the proper mix of new or alternative practices or technologies that work in each unique circumstance.

Third, a complete solution that requires both improved management of both demand and supply side of the equation. We must be doing a better job investing in water infrastructure and capturing water resources when they are available. Water infrastructure and investment should also be made more attractive and affordable for non-Federal interests.

Access to broadband will help ensure availability of on-demand regional, statewide, and national weather resources, and is foundational for irrigations scheduling and other on farm decision making. We recommend that Congress work with the U.S. Department of Agriculture, the Federal Communications Commission to fund programs to solve these critical rural broadband problems.

The Farm Bureau appreciates the time and attention that the Subcommittee has given to this important topic today, and I am happy to answer any questions. Thank you for letting me go over a minute.

[The prepared statement of Mr. Cameron follows:]

PREPARED STATEMENT OF DON J. CAMERON, VICE PRESIDENT AND GENERAL MANAGER, TERRANOVA RANCH, INC.; OWNER, PRADO FARMS, HELM, CA; ON BEHALF OF CALIFORNIA FARM BUREAU FEDERATION

Introduction

Chair Spanberger, Ranking Member LaMalfa, and Members of the Subcommittee, thank you for the opportunity to appear before you today on the important topic of realizing the conservation benefits of precision agriculture. I am Don Cameron, Vice President and General Manager of Terranova Ranch located in Helm, California. I am also the Owner of Prado Farms located in Fresno County, California.

In addition to farming, I currently serve as the President of the California State Board of Food and Agriculture and as an appointed member to the California Department of Food and Agriculture's Environmental Farming Act Science Advisory Panel. I also serve on the Board of Directors for the McMullin Area Groundwater Sustainability Agency and the Raisin City Water District.

I am testifying before this Subcommittee on behalf of California Farm Bureau Federation. Farm Bureau is a nonprofit, voluntary membership organization whose purpose is to protect and promote agricultural interests throughout the state of California. Farm Bureau is California's largest farm organization, representing nearly 36,000 members across 53 counties, contributing to the largest agricultural economy of any state in the nation. Farm Bureau strives to protect and improve the ability of farmers and ranchers engaged in production agriculture to provide a reliable supply of food and fiber through responsible stewardship of California's resources.

About Our Operation

The Terranova Ranch was established in Helm, California in the early 1980s. At that time, the prominent crops grown were upland cotton, alfalfa hay, wheat, and barley. The first vineyards were planted in 1981 and in the late 1980s and 1990s the variety of crops grown increased to include corn silage, sugar beets and pima cotton. In 1991, we began growing processing tomatoes with a little over 5,000 tons produced. At that time, our tomatoes were grown by planting seed and practicing furrow irrigation where trenches, or furrows, are dug between crop rows in a field. Today, we use transplants and subsurface drip irrigation for the 140,000 tons of tomatoes we grow each year.

I will also add that in 1993, we began farming organically with 15 acres. Presently we have over 600 acres in organic production. In 2000, we began further increasing our variety of crops grown to our present number of over 25 different crops on 6,000 acres.

In 2018, Terranova Ranch, Inc. was recognized with the State of California's highest environmental honor, the Governor's Environmental and Economic Leadership Award (GEELA), for its efforts in pioneering and expanding the practice of on-farm groundwater recharge—intentionally flooding fields with captured floodwater to replenish depleted aquifers. Established in 1993, GEELA is awarded to individuals, organizations and businesses that have demonstrated exceptional leadership and made notable, voluntary contributions to conserving California's natural resources, protecting and enhancing our environment, building public-private partnerships, and strengthening the state's economy.

In 2016, Terranova conducted a study where we calculated the calories produced by our operation. Our study concluded that Terranova Ranch is able to feed 200,000 people a 2,000-calorie diet for a year just with what our operation produces. I am very proud of the safe food supply and nutrition our farm produces.

Practices Implemented on Our Operation

At Terranova Ranch, we have concentrated our attention on methods that keep our soil, water, and air quality as sustainable and healthy as possible. More specifically, we have focused on methods and techniques on water recharge, irrigation efficiency, energy conservation, energy production, and farm equipment with cleaner emissions. Our end-goal is to maintain our operation's long-term viability with adequate water, clean air and healthy soil.

As a diversified farming operation, our techniques make certain that our soil never gets fatigued. This means that we plant a variety of different crops on our ranch that are designed to work together. We grow crops year round by replanting fields with crops that thrive in the coming seasons. This also helps stop soil erosion while keeping the ground fertile. Another advantage of diversified farming is that no single crop makes up more than 1/3 of our income. This helps insulate our operation from poor production years, crop price reductions and disasters.

The multitude of sustainable development principles, practices and technologies we implement on the ranch preserves our soil and allows it to be fertile, maintain-

ing both plants and wildlife. These practices also encourage our biological systems to be productive, beneficial and diverse. Our practices include the following:

- **Water Recharge**

For over 25 years we have been working toward recharging the underground aquifer below the ranch, our main source of irrigation water. In 2011, floodwater was applied to farm fields and documented by researchers at Bachand & Associates and UC Davis. In 2012, the Kings River Conservation District (KRCD) was granted \$5 million from the California Department of Water Resources along with \$2 million in matching funds from Terranova Ranch to build infrastructure in order to capture and distribute floodwater to Terranova and nearby farmland for on-farm recharge. Sustainable Conservation and UC Davis have been partners in this project. Work is progressing to implement this project which, at full capacity, will be able to recharge up to 1,000 acre-feet of floodwater per day on 18,000 acres of farmland. This project will be a perfect fit with the sustainable groundwater management plan for our area and we believe it showcases our commitment to long-term sustainability goals for farming in the San Joaquin Valley.

- **Drip Irrigation**

In 2009, Terranova Ranch began irrigating with subsurface irrigation on most of its annual crops. By making this change, Terranova was able to reduce water usage by 30% while increasing yields by 25%.

- **Energy**

Terranova Ranch started with a 1 megawatt solar facility on 10 acres of land. By 2016, the ranch brought an additional 1 megawatt facility online. With the completion of a these solar projects, renewable energy provides 1/3 of our electric needs while reducing greenhouse gas emissions by 3,700 tons CO₂ per year.

We have also upgraded our sprinkler irrigation systems from impact sprinkler heads to new water and energy saving plastic sprinkler heads. The new sprinklers use less water by having better uniformity and are more efficient. We are able to conserve water and lower our energy usage, conserving resources and the environment.

We have also achieved greater sustainability through our pump motors. The use of Variable Frequency Drives (VFD's) reduces the amount of energy needed for the pumping of water. All pumps equipped with VFD's require only the amount of energy needed for the water volume desired. This is a much-needed improvement from the old practice of running a pump at full power even when unnecessary. In addition to these changes, we have also converted from diesel to electric booster pumps at all wells with VFD's.

- **Ecosystem Services**

The California Department of Food and Agriculture's (CDFA) Science Advisory Panel defines ecosystem services in agriculture as *"the multiple benefits we gain from farming and ranching including crop and livestock production. In addition to valuable open space and wildlife habitat, the management decisions and conservation practices of farmers and ranchers also enhance environmental quality, provide recreational opportunities, and offer social benefits."*

We support goals and methods of farming aimed at maintaining a diverse habitat on the farm. Wildlife helps our farm by providing necessary pest control and contributes to the diversity of our environment. We have partnered with the National Audubon Society to promote habitat for wildlife by placing owl boxes throughout our fields. We also maintain 4 acres of wildlife refuge that is a home to egret and cormorant rookeries, pond turtles, frogs, ducks, great blue herons, hawks, short eared owls and other wildlife.

We have also planted about 1 acre of milkweed on the farm to support monarch butterflies that migrate through our area. In addition, we are beginning a project to establish hedgerows of native pollinator habitat on approximately 2 miles of levee on the farm.

- **Air Quality**

We continue to strive to make many improvements to help keep our air clean and reduce pollution. These improvements include the conversion from natural gas motors to cleaner electric motors. We are also enrolled in the San Joaquin Valley Air Pollution Control District Incentives Program which has helped us replace older Tier 1 and Tier 2 diesel engines on our tractors with cleaner, more efficient Tier 4 engines. Today, almost all of our equipment on the farm has been converted over to cleaner Tier 4 diesel engines. We have also switched 13 All-Terrain Vehicles from gasoline power to electric.

Considerations for the Subcommittee

I was asked by the Subcommittee to focus my comments on precision agriculture as it relates to agricultural irrigation and water certainty. I wish to raise several items I feel are important for the Subcommittee to be aware of as you consider Federal policy relative to conservation and precision agriculture.

- Precision agriculture provides optimal benefits when executed at scales that recognize the limitations and capabilities of tools to effectively manage a full array of connected variables including, but not limited to, topography, biological demands, agronomics, and natural environment conditions. Therefore, it is essential that farms have the opportunity and flexibility to try new ways of farming that might improve conservation.

For example, on our farm, we have had success simply trying out new approaches in order to conserve water, improve air quality, and reduce energy consumption. We research a new opportunity, trial a new practice for a determined amount of time, test things on small plots in a controlled manner in order to measure the results. If proven successful, we are able to ramp up production on a larger test plot and ultimately adopt the practice across the farm. While we have had great success in some areas, we have not had success in all areas. The adoption process can also be extremely costly and time consuming. Additionally, practices that work for our operation do not necessarily work for a neighboring operation or another farming region.

- California's farmers and ranchers are at the ready to adopt new technology and precision agricultural practices, but it is critical that these technologies and practices are readily available, scientifically trialed and affordable for the operation and crops being grown. In the area of irrigation, the most common irrigation methods used in California are gravity (furrow or flood) irrigation, sprinkler irrigation and drip irrigation. Farmers choose their method of irrigation based on a series of factors including, but not limited to, soil type, topography, and the crop.

California agriculture has experienced a great level of adoption of pressurized irrigation systems such as surface drip irrigation or sprinklers. These pressurized irrigation systems generally apply water at a slow and accurate rate providing the farmer an immense amount of control. However, these systems are much more costly to install and operate than furrow irrigation techniques and may not be economically feasible for every crop or operation. Additionally, such technologies and systems may rely on a skill sets not readily available and additional investments in training or certifications must be made.

Regardless of irrigation method, all irrigation systems have the potential to be operated inefficiently. For that reason, a producer focusing on an irrigation management plan that is efficiently operated, rather than irrigation method, is most important.

- Scientific irrigation scheduling is an important component in California's modern farming operations. To prevent this, farmers use a variety of tools to help them determine when to irrigate including, but not limited to, the weather, soil moisture, and the plant's stress level. In California, farmers have the ability to utilize the California Irrigation Management Information System (CIMIS), a network of more than 145 automated stations across the state that gather weather data. Managed by the California Department of Water Resources, this system assists farmers with gauging the amount of water their crops need.
- It is essential that there is an understanding of the difference between "water conservation" and "water use efficiency". These terms are often used interchangeably but to agricultural water users they are very different things.
 - *Water conservation* is generally perceived as an activity that reduces the amount of water used to do something, such as wash a load of clothes or take a shower. High efficiency washing machines and low-flow showerheads *conserve* water that can then be used by another user or at a later time.
 - *Water use efficiency* is when a water user does things to achieve more using the same (or less) water. For example, a farmer who changes their irrigation system so that water is more efficiently used by the crop, producing more saleable, higher quality crop on roughly the same amount of water. The *efficiency* is what is gained in crop production.
- While there are many advantages to implementing precision agriculture via efficient irrigation practices, we must also be cognizant of trade-offs and unintended consequences that can exist with resource decision-making. Water and energy are tightly linked. Installation and use of industrial pumps and motors,

on-demand pressurized drip lines, tailwater recovery and recirculation of water for reuse can result in increased energy demand. Additionally, some producers could experience a time-shift on when energy demands occur. For example, soil moisture and plant stress monitoring can shift energy use to daylight/peak-time demand away from off-peak.

It is common knowledge that California continues to experience water uncertainty. Therefore, California's farmers and ranchers must be careful stewards of the water utilized to produce food and fiber. Though precision agricultural practices have assisted agricultural producers with reducing their consumptive water use, the unintended consequence has been less water returning to the system. In some areas, this has resulted in dramatic impacts to underlying groundwater supplies, which do not receive adequate recharge resulting in overdraft and subsidence.

This is highly relevant in the context of California's Sustainability Groundwater Management Act, which is expected in coming years to dramatically reduce the amount of groundwater that can be relied upon for irrigation in time of drought or reduced surface water deliveries. This will place a premium on efficient use and management of available water through means including new and existing technologies. At the same time, it will require expanded recharge and capture of excess flows in times of abundance. A complete solution, therefore, requires both improved management of both demand and supply sides of the equation.

Recommendations for the Subcommittee

In light of the considerations offered above, I offer the following recommendations to the Subcommittee for consideration:

- **Continued Investment in Voluntary Cost-Share Programs for Producers**

We are very appreciative of the many improvements that were made by this Committee in the conservation title of the last farm bill. Of the conservation title programs, the Environmental Quality Incentives Program (EQIP) is by far the most utilized program in California assisting producers in achieving greater conservation goals. We particularly thank you for including funding for air quality incentives, which has been incredibly important to farmers in California who face strict air standards. EQIP has assisted farmers in making great strides in the areas of air quality and water conservation and we believe there is more to come.

- **Continued Investment in Technical Assistance**

Financial resources for Natural Resources Conservation Service technical assistance staff at levels commensurate to the voluntary financial assistance are essential for assisting producer adoption.

- **Flexibility**

It is important to recognize that there is no one-size-fits-all approach for precision agriculture practices. In California alone, there are over 400 commodities grown. Each field, crop and operation will have different conservation and economic needs to factor in and we need to realize that, in some circumstances, the practices that have been promoted and validated in one field might not make sense for the next. We must be cautious in making value judgments and use our motivation and resources to identify the proper mix of new or alternative practices or technologies that work in each unique circumstance.

- **Limited Control**

Farmers have only so much control. California's farmers and ranchers continue to farm amidst great uncertainty when it comes to reliable water supplies. Despite recent improved water conditions, periodic drought is a fact of life in California. The severe 2012–2015 drought followed by the wet years since has illustrated what both extended drought and extreme rainfall cycles look like with inadequate water infrastructure. If longer and drier droughts coupled with powerful floods are the future of California's possible larger climate trend, it means we must do a better job of investing in water infrastructure and capturing water resources when they are available. This in itself is a way of maximizing efficient use of limited water resources across different year types.

- **Federal Investment/Innovative Finance Tools**

Water infrastructure investments should be made more attractive and affordable for non-Federal interests. For that reason, Farm Bureau has been supportive of expanding Federal financing mechanisms. We believe the combination of Federal funding and common sense financial tools, such as the creation of

the Reclamation Infrastructure Finance and Innovation Act (RIFIA) loan program, would greatly aid western water managers with the construction, rehabilitation and improvement of surface and groundwater storage projects, conveyance, as well as water recycling and desalination projects. The Natural Resources Conservation Service Regional Conservation Partnership Program (RCPF) is also an excellent program.

- **Broadband**

A critical component to implementation of precision agricultural technologies is access to broadband. Despite our apparent proximity to Silicon Valley, there are many areas, myself included, of rural California that do not have sufficient access. Many rural areas either lack the initial infrastructure or have fallen behind in terms of speed and availability. It is critical that investments are made and unfortunately, in our experience, many providers are skewing their data, which creates inaccurate maps of dead zones.

Technology can provide many benefits and increase efficiency in agriculture—but only if its available to agricultural regions and our rural communities. We recommend that Congress work with the U.S. Department of Agriculture and the Federal Communications Commission to fund programs to solve these critical rural broadband problems. Access to broadband will help ensure availability of on-demand regional, statewide, and national weather resources that are foundational for irrigation scheduling & other on-farm decision-making.

Conclusion

California's farmers and ranchers are water stewards, using water to grow the crops that feed and clothe us. California's 77,500 farms and ranches produce 50 percent of the nation's fruits, nuts and vegetables; twenty percent of the milk; and more than 400 different agricultural commodities. California's farmers have long been early adopters of new and innovative technologies that can help produce food and fiber more efficiently and that tradition continues today.

Farm Bureau appreciates the time and attention that this Subcommittee has given to this important topic today and I am happy to answer any questions. Thank you for the opportunity to testify.

The CHAIR. Thank you very much to the witnesses for their initial testimony. Members will be recognized for questioning in order of seniority for Members who were here at the start of the hearing. After that, Members will be recognized in order of arrival.

I will first recognize myself for 5 minutes, and I would like to begin by thanking Mr. Madison for making reference to the conservation efforts that have been vital across the Commonwealth of Virginia in restoring the Chesapeake Bay, and the important role that farmers and producers have played in that ongoing work that we are doing, just next door, in Virginia.

Mr. Cameron, you mentioned broadband internet, and that farmers can reap the benefit of a full range of options afforded by precision agriculture, and that without connectivity through rural broadband, there are hindrances. Even in areas with broadband access, the internet connection speed is not always fast enough or predictable enough to support precision agriculture technology. Can you speak to the importance of high-speed internet in maximizing conservation efforts, and as we here in Congress considering policy approaches that help expand broadband access and enable the uptake of precision ag tools, is there anything in particular that you think we should keep in mind?

Mr. CAMERON. Thank you, Madam Chair.

Broadband is a near and dear problem that I take very seriously. On our farm, we are probably 100 miles away from the Silicon Valley. We are lucky to get 4 megabits up and down on our farm, which on most days, is somewhere around 2. It is like a dial-up service it is so bad. We have poor telephone connection with cellular within our operation. But with broadband, we can inter-

connect our whole farm. We can monitor wells. We can monitor flow rates. We can turn on and off wells, irrigation systems, from our phone. But without the access, not only do we suffer as a business and are at a disadvantage, but also our rural communities that have children that are moving on to college can't even fill out a college application online, because of the poor broadband service.

I just feel that this is extremely important for precision agriculture. We need to be connected and somehow, the rural economy has been left out of the picture. When I hear of 1 gigabyte in some cities in California, I just can't believe that we can't do better.

The CHAIR. Thank you very much.

Mr. Madison, in your work as a farmer, consultant, and a member of multiple advisory committees, which Federal programs that aim to facilitate the adoption of precision agriculture tools do you see as particularly relevant in central Virginia, and how could these programs be improved, in your opinion? And I also welcome you to comment on the question I posed to Mr. Cameron related to broadband, and how lack of accessibility, lack of access in Louisa County impacts your day to day work?

Mr. MADISON. Thanks.

I am going to start with the broadband. I am looking at it a little bit differently and say that a lot of what we use internet access for in precision ag on our farm is the work that happens after the season and before the season. That is where all the planning comes into play that makes the precision ag piece work in the field. That is a lot of internet usage. I can't take my laptop and sit in McDonald's all day to find WiFi to do this kind of stuff. Our business depends on it, so it is very important that we have a way to use the tools that we invest money in, that we take the time to learn, and get the most out of what we are doing.

To the conservation programs, precision programs, EQIP has always been really good to us. It fills a lot of needs. It covers a lot of ground if you have the whole EQIP playbook to work with. Sometimes, at least in my experience in Virginia, we don't always have that whole playbook to work with. I guess on the downside of that is when it comes to some of the CAT plans for nutrient management, the technical service provider stuff, that is promoted from NRCS. Well, at the Federal level, it doesn't really get promoted at the state level. I have been a TSP for either 4 or 5 years. NRCS personnel has directed me to write three plans. That is not a lot. There is a lot of opening for it. The plans that I have written, everybody was really into it. They were glad they were getting something, because if they didn't have that, they would have gone back to old style practices, throw a bunch of fertilizer out there, see what happens.

We have really good programs. We just need a little bit more follow through on them at the state level.

The CHAIR. Thank you very much.

I now recognize Ranking Member LaMalfa, for 5 minutes.

Mr. LAMALFA. Thank you again.

Mr. Cameron, let's just get to the nuts and bolts of this. How is conservation associated with or helped with, as we see farm income struggling, and the condition of agriculture in this country is pretty

rough. How has conservation helped with your bottom line, going forward?

Mr. CAMERON. I know that when we adopted subsurface drip irrigation on our farm with precise application of nutrients, insecticides, and water, that we actually found our water use decrease by 30 percent, and that our yield increased by 25 percent on processing tomatoes. We did a 1 year trial in 2009, and then in 2010 we converted every acre we had of tomatoes and started with some of the other crops to subsurface drip irrigation. Yes, we had an immediate benefit from that. We were ahead of the curve, so we were able to capture better income for quite a few years before the rest of the industry caught up with what we had done. That allowed us to purchase new equipment with cleaner engines. It was almost like a snowball effect. Once we got started down that track, it gave us additional income that we could spend to improve other operations of the farm.

We found that some of these precision techniques have been really beneficial to us over the years.

Mr. LAMALFA. Thank you.

Mr. Madison, do you care to add to that?

Mr. MADISON. I would say the same thing in a lot of regards, especially in there were some initial advantages to going down some conservation routes. But over time, they get amplified. No-till gets better as you stick with it. Cover crops in a field get better as you stick with it. More targeted fertilizer application typically saves you money more each year you do it. There is a lot of opportunity for that to build on itself. I would say it is a really big deal in what we do.

Mr. LAMALFA. Thank you.

I note that on the fertilizer application, if you can tailor it to what the need is, you get uniformity of yield or you get closer to that, which helps with ripening and timing on harvest.

For both of you here, do you feel that the current voluntary conservation programs are adaptable at this point to your conservation needs these days? Are they as adaptable as you need, or do we need to do more work?

Mr. CAMERON. The programs that—a lot of the conservation programs, those Conservation Reserve Programs really haven't been that effective in California and the typical agriculture production areas, because we tend to farm every square inch that we have. We just feel that that is the way we need to be to be profitable. We have taken a slightly different approach to that lately, and are dedicating part of our farm to different pollinator habitats. We have a monarch project where we put in milkweed with Environmental Defense Fund. We have made partnerships with sustainable conservation, UC Davis, some of the universities to do some additional precision work on the farm.

But, like I said, we think EQIP is great. We think the RCPP Program is excellent for a larger area, bringing farmers together for one goal. We think it is a very effective way to bring new infrastructure on farm and onto the region.

Mr. LAMALFA. Mr. Madison, do you agree or how does that look for you?

Mr. MADISON. Yes, definitely. Voluntary conservation efforts, even if they may be incentivized from EQIP or RCPP or any other thing that we can find, they are all beneficial. You don't have to twist people's arm too much to get them to go down that route of some conservation practices. Once they see a year or 2 down the road that they did realize an advantage.

Mr. LAMALFA. I agree. Okay.

I yield back, Madam Chair. Thank you.

The CHAIR. Thank you.

I now recognize the gentleman from Arizona, for 5 minutes.

Mr. O'HALLERAN. Madam Chair, thank you for scheduling this hearing on the important conservation benefits of using precision agriculture.

The University of Arizona operates the Maricopa Agriculture Center in my district in partnership with the USDA. The MAC is dedicated to developing and delivering the best integrated agriculture technologies for problems faced by Arizona consumers and producers.

One example of their work includes using drones equipped with special imaging sensors to monitor crop development. This technology provides researchers with more precision information on the crops condition.

I have scratched out a lot of my statement here because what I have heard is—I am concerned with what I have heard today. It is like rural Arizona has been—America has been forgotten in the technology and knowledge-based economy. My district is the size of Illinois. I go around my district and 50 percent of the time not only can't I connect to the internet; I don't have cell coverage at all. And that is a problem in the West especially. You go down in a valley somewhere, even if you are close to town, you are missing it. I heard Mr. Madison easily describe getting to a McDonald's, and many of the towns in my area, McDonald's is the after-school program to get on to the internet.

I don't understand a country that was able to get telephone to every bit of this country is in this situation today, and if we expect the people of rural America to do what we need them to do and keep them there and allow them to have a quality of life, then we have to do something much better than we are.

Now, urban America, with all this high speed and everything, they get their water from rural America, their food from rural America, their energy from rural America. The whole concept of transportation, that is where their—in many cases, their vacation home is at. That is where they go on tourism. And we have to have people out there. They don't need to be moving into cities. And yet, we have our young people, after they get out of college hopefully, if they are able to get there because of lack of educational opportunity, we have them going to cities in order to find jobs and leaving farming and the agriculture industry.

Our country can't afford to go down this path any further, and I am glad we had this hearing today, but it has to—we have to start to acknowledge as a body that we just aren't going in the direction we need to be going.

I struggle. I go to the research center twice a year, and find that all this stuff that they are doing is for naught. People just aren't

able to use it if you are further away from a city or town. And there is—I see no real program here in Congress that has adapted to the realization of this. They are under-funded programs, whether they are the USDA or out of any other Committee here. They are not coordinated. We have to have numerous people out there being told when we know people want it and need it that it is just too costly to get out there. And with 5G coming along, people are going to be—demand even higher speeds. Tremendous amounts of money are going to be put into this. And so, if there is a gap between rural America and urban America, that gap is only going to increase. And that is something that I just don't want for the children of rural America. I don't want it for the—our rural communities, our agriculture communities.

And so, I am not going to ask any questions. I am going to yield back and thank the panelists for being here today.

The CHAIR. I thank the gentleman from Arizona for expressing a frustration that I think is shared from any of us who represent rural communities throughout the country.

I now recognize Ranking Member Conaway, for 5 minutes.

**OPENING STATEMENT OF HON. K. MICHAEL CONAWAY, A
REPRESENTATIVE IN CONGRESS FROM TEXAS**

Mr. CONAWAY. I thank the Chair.

Dr. Karsten, the land-grant schools are the best way that we communicate research and other things to actual producers. Can you talk to us about the kinds of resources the land-grant schools provide for our producers in translating all this technology and precision agriculture into actual operations on their farms and ranches? What role are you all playing in that regard?

Dr. KARSTEN. Yes. I think that the first opportunity or what we do is to train students, to teach students, and we have graduates who, as soon as they are finished with their degrees, they are hired to work in this area of conservation and precision agriculture. And so, that is an important role that land-grants provide in preparing people for the workforce. And there are lots of opportunities to do more of that. There are some online education types of programs that broadband would be needed for, but that can reach a broader audience.

In terms of research, we are producing free online decision support tools and access to data that is gathered through, for instance, remote sensing or satellite imagery. If a farmer can't afford the sensors to create a yield map to put on their combine, there are tools in the satellite vegetation index that we can use to create these yield maps to help them do more precision management and identify opportunities to increase their profitability and optimize conservation.

Mr. CONAWAY. I guess that was the question. You have those tools; you have those resources. How do you get that communicated to the producers out there? Through extension? How does that producer know, or do any producers know that that is available for their region?

Dr. KARSTEN. Right. The partnership with extension and researchers and with extension and other educators like the NRCS and consultants, crop consultants, nutrition consultants, is key.

And there are more opportunities and quite honestly, I think the need for more funding to extend those activities and expand those activities to reach more growers and more practitioners or consultants with these tools. Some of these tools were still identifying how to optimize the interface, the user-friendly access, and that kind of dialogue between the users, the educators, researchers, is key. There are opportunities for on farm research for extension to help farmers evaluate these technologies, and then to facilitate peer-to-peer learning. We know that farmers are more comfortable adopting something if it has been successful for their community and their neighbors, and often support just to help bring farmers to different educational events can be very impactful.

And just helping them—I mean, I have had—I have talked to colleagues who say someone invested a lot of money in this technology and then they couldn't use it because they couldn't figure out how to download the right software and sync it to their database computer and their monitors, their combines, their planters. And that kind of technical assistance—which we need to teach our students to do, but also help our educators, our extension providers provide that is critical.

Mr. CONAWAY. Thank you.

Mr. CAMERON, you used a phrase that I was not familiar with, “pressurized irrigation systems.” Would you explain to me what that is? And you also said, “pressurized drip.” Is that the same thing?

Mr. CAMERON. Typically it is the same thing, because when you do drip irrigation, you do need to pressurize your system. It could be low pressure. It may only be 10 or 12 pounds per square inch, and we also use precision highly efficient sprinklers for some of the crops that we grow, carrots and onions, that require sprinkler application.

Yes, when we pressurize, it takes energy to run those booster pumps to drive the system.

Mr. CONAWAY. The sprinklers, you need pressure more than just the normal load from your source?

Mr. CAMERON. Right, right, because we pump almost all of our water from the groundwater.

Mr. CONAWAY. Okay.

Mr. CAMERON. We bring it up and then we have to add another pump to take it up for sprinklers up to 60 pounds per square inch.

Mr. CONAWAY. I got you. Thank you.

Mr. CAMERON. Sure.

Mr. CONAWAY. Thank you very much, Madam Chair. I will be remiss if not referring our folks to the 2018 Farm Bill that did have extensive broadband activities in there. It requires coordination between FCC and USDA on the ways that they are trying to get at this, but I concur with my colleagues that without it, we are going to keep rural America behind the curve on that. But we have taken a look at it.

I yield back.

The CHAIR. Thank you.

I now recognize the gentlewoman from Maine, for 5 minutes.

Ms. PINGREE. Thank you very much, Madam Chair. Thank you for holding this hearing, and to all the witnesses for being here today.

Just so Maine isn't left out, I want to make sure that I concur with all my colleagues on the challenges of broadband. We are the most rural state in the nation. We are always in the bottom ten percent of connection and speed, so we feel everyone else's pain. And while I have been a part of working on things like the farm bill and more appropriations, there are some structural issues that continue to keep rural America from being connected. And some of it just has to do with our system of providers who just don't want to go that last mile—sometimes it is the last 20 miles—to get out there. We have to take a much more serious look at this. But thank you for what you are talking about.

In my state, for the most part we have a lot more small to medium size farmers, and some of what you are talking about requires a big investment. Can you talk a little bit about which of these applications you think apply or are useful, or could be converted for use for small to medium sized farmers? And also, I guess you have talked a little bit about it, but just the continuing need for technical assistance. Farmers can't all be data managers and operate all this equipment. I think you are talking a little bit about that, and I know some of you are even playing that role.

But anyway, just a little bit more about is there value for other farmers?

Dr. KARSTEN. Was that—

Ms. PINGREE. Anybody.

Dr. KARSTEN. I would offer that we know that we can help farmers have access to yield maps to better site specific manage subzones or subfields without necessarily having only the yield monitor maps. And that is an example of how there are opportunities for farmers of all different sizes to then fine tune their management and make sure what they use in that location is profitable and that it is going to be profitable in the long-term.

If they can adopt more diverse rotations and conservation practices like reduced tillage and continuous cover, they can retain more nutrients on their farm. They can interrupt pest life cycles, provide habitat for beneficials, and there are multiple benefits that come with these conservation practices, like soil health and resilience to stress.

I will defer to others.

Ms. PINGREE. Well, let me throw in another question, unless one of you is about to—were you about to answer that?

Mr. CAMERON. I wanted to just mention one other thing on broadband.

We were approached by a large company for bringing broadband in. Since nobody ever comes to us and tells us they are going to do that, so of course, we said, "Sure, let's do it." They came back to us and told us that it would be \$850,000 to bring 20 down dedicated to our operation.

So of course, we didn't do it.

Ms. PINGREE. Yes. I mean, we hear a lot of stories about that, \$10,000, \$20,000, \$50,000 to get it to a rural community.

Mr. CAMERON. Unbelievable.

Ms. PINGREE. Yes, and \$850,000 is sort of off the charts.

Mr. CAMERON. Yes, I was just going to echo your—the technical assistance providers are critical to get this information out to the growers, to their level on farm projects, anything they can do to help the growers adapt is beneficial. I think it is an integral part of the NRCS program.

Dr. KARSTEN. I would add that, in Pennsylvania, we have a lot of people who don't use the internet, Amish and other cultures. And so, we know that we need to produce hard copy educational materials and do field events and conferences in the communities, work with growers through extension educators. And that is also really face to face, on the farm, really site-specific kinds of work that extension can—does and can do more of, and we have tools that you don't need a computer necessarily. You can use pen and paper.

An example would be one of my colleagues who is helping farmers better manage their nitrogen by crediting the fact that they have built soil organic matter and that they have cover crops in the system that are retaining and supplying nitrogen to the crops, so that they don't have to buy an input to supply that nitrogen. There are other tools like that. Yes, they are online, but they also are in the forms that we can use in the field. And that is the important opportunity with extension.

Ms. PINGREE. That is great. I am about to run out of time, but thank you so much for your testimony and the work that you are doing out there. Thanks.

The CHAIR. I now recognize Mr. Allen from Georgia, for 5 minutes.

Mr. ALLEN. Thank you, Madam Chair, and I want to thank the panel for being here today, and commenting on this amazing technology that is driving the largest industry in my state, agriculture, and the largest industry in my district.

Dr. Karsten, as you know, we have the University of Georgia there in the state. It is a land-grant institution, and their researchers are committed to helping farmers maximize crop yields while minimizing their resource usage. And precision agriculture plays a key role in that.

Can you provide a brief overview of what type of resources land-grant universities like Penn State and the University of Georgia can provide for our farmers when training them to adopt these practices on the farms? In other words, how do we get it from the research to the farmers, and how do we do that with the bottom line that they are working with right now?

Dr. KARSTEN. Well, some of the extension activities that we do with farmers on their farms to help them evaluate technologies, but also to adopt these new decision support tools or these technologies are critical. Often they need assistance, both in terms of the technology, but also in interpreting what the recommendations are from, say, a decision support tool and technical assistance.

We see a lot of our graduates are the people who go out and provide that technical assistance, and it is not only through extension—although that is a very critical role—but because they go to work in the workforce and other agencies. And that partnership that land-grants provide to work with input providers or the folks developing some of this technology can keep the communication

about well, how do we make this available and accessible? And how do we make this a tool that they could use online or that they could use on their phone? There are lots of apps, for instance, that we are producing so that a farmer on their phone can integrate what is the cost of this feed or this input, and what are the potential ways they could save money and increase their long-term productivity.

Mr. ALLEN. That is what technology is all about, which kind of brings me to my next question.

Each of you have talked about the barriers to adopting this precision agriculture in your testimony, and what steps can this body, United States Congress, do to help reduce these barriers? For example, obviously we have talked about how it sounds like your biggest challenge is cell phone service and broadband, and the costs associated with delivering that service to deliver precision ag. Is that what I am hearing? Would Mr. Cameron and Mr. Madison care to comment on that?

Mr. CAMERON. Yes. We know that when we—we do aerial photos every week of our crops during the season when they are growing, and if it takes us 2 minutes to download a photo of one field, our time is precious. I mean, we have a lot of things going on at the same time, and it makes it difficult to do the work that we need and to bring the technology onboard so that we can affect change in the field with either nutrient levels, water delivery. It is a big stumbling block for us. And I don't mean to belabor it, but it is a serious issue in the rural community because we get bombarded with tech companies from Silicon Valley that want to cure problems we don't even have, but we do—we just have seen a lot of projects come our way and we tend to be the one that filters them out, whether the ones that sound promising we try. Others, we show them the door. But there is a lot of technology that is coming into agriculture.

But, yes, we need a different caliber of employee coming on farm that knows how to handle and implement technology that is available.

Mr. ALLEN. That is why it is important to support our young farmers.

Mr. CAMERON. Exactly. I agree.

Mr. ALLEN. I yield back. I am out of time. Sorry, Mr. Madison, you can comment on that next time you are asked a question.

The CHAIR. Thank you, Mr. Allen.

I now recognize the gentlewoman from Iowa, for 5 minutes.

Mrs. AXNE. Thank you, Madam Chair and Ranking Member, and thank you for holding this very important hearing, and thank you so much to our witnesses for being here today. I am very grateful to have you here.

I won't belabor the point of broadband, even though that is one of my questions, but I would encourage all of you to continue to promote it. I am on the Whip's Rural Broadband Taskforce. We know how important this is, and by gosh, we are determined to make sure that this gets out to rural America on so many levels, from precision agriculture to keeping people healthy. Please, the more voices we have in this, absolutely the better. We would love to hear it.

I want to just go back to another topic related to some of the natural disasters that we are facing and the impact on agriculture.

We all know that farmers have always been on the cutting edge of technology in utilizing new advances to increase efficiency and yields, while using less inputs. Over the last few decades, we have seen a heck of a lot of movement in this. We have seen farms integrate satellite technology to better manage their acres and to make smarter decisions with better information. And since 1960, the average yield per acre of seed corn has more than tripled, largely due to improved technology and adoption of precision ag, which has led to significant benefits for conservation by reducing inputs, leading to less waste and more efficient use of energy.

The benefits of precision agriculture are clear, and I am glad we are here today to discuss that and what we can continue to do further when it comes to resiliency.

If you haven't seen the news lately, farmers in my district have had a real tough year. I am from Iowa's third district, with issues of low commodity prices being exacerbated by a trade war, and of course, a biofuels program that is being undermined. And on top of this, we have had record amounts of water, and then some of the worst flooding we have seen in my district, it has literally been the most historic flooding. We are in bad straits there.

The flooding has devastated communities around the Missouri River, and resulted in over 100,000 farm acres being flooded and billions of dollars of damage. And while of course flood prevention is our number one priority and making these folks whole and making sure that we cover things like uninsured grain bins, we must also be prepared for recovery and work to improve resiliency.

Dr. Karsten, I am wondering, farmers in my district and across the Midwest have seen changing rainfall patterns in recent years, and as farmers adjust to unpredictable weather and changes in precipitation, how can precision agriculture technology help our farms grow more resilient against these issues?

Dr. KARSTEN. Yes. I think that the example of using the landscape variability to identify regions that are most vulnerable to extreme weather events, that have shallow soils, low organic matter, *et cetera*, and have not yielded profitably consistently over time is an excellent example of how those regions can be managed specifically for best long-term productivity and profitability. And so, that might mean that a farmer can identify a zone that is in a flood plain or that is very shallow and on a steep slope that would be better served than the typical annual crop rotation that they have by planting perennials that once they are planted, they are established for many, many years. And they can retain water and nutrients; but, with those deep root systems and maintain productivity either for forages or biofuel, energy crops, or bedding, and still produce a profitable product in a region that they would have actually been losing money and would have frequently experienced the impacts of these extreme weather events.

That kind of site-specific opportunity is prime, and there are lots of examples of research in Iowa that have identified these zones that are losing money, very significant losses that can be overcome with site-specific management and things like perennials or con-

servation practices that build soil health and increase water infiltration and resistance to or resilience to stress.

I want to defer.

Mr. CAMERON. When I look at resiliency in agriculture, we look at healthy soils. We know that we can build increased organic matter, sequester carbon, ways that we can hold water longer, which you may not have wanted this year. But in California, we went through a 5 year drought and believe me, every drop of water we want to hold either above ground or below ground for use at a later time.

But, with better soil health, I think you can control your nutrients. They are not going to be leeching. There are just great ways that you can increase production. We are looking at in California at a program of incorporating a whole almond orchard at the end of its life, chipping it, and putting all of that biomass back into the ground so that carbon will be sequestered and you will have additional organic matter long-term. We are working in California the same as you do at the Federal level to improve soil health.

Mrs. AXNE. Thank you. We would trade water with you any day if we could.

Mr. CAMERON. We would love it.

The CHAIR. Thank you, Mrs. Axne.

The Chair now recognizes the gentlewoman from Washington State, for 5 minutes.

Ms. SCHRIER. Thank you, Madam Chair, and thank you for letting me crash your Subcommittee twice in about a week here. I want to thank you all for being here.

Mr. Madison, you raised a really interesting topic that I hope you can expand on. It is the use of the TSPs, the technical service providers to support NRCS staff in the field. One of the things that I routinely hear from my farmers who are trying to do the right thing with resilience farming and healthy soil and drill seeding machines is that they need additional technical assistance to help them enroll in conservation programs and then do the work.

I was wondering if you could speak about your experience and what technical service providers can offer farmers?

Mr. MADISON. A TSP is basically a privatized NRCS employee. We can write the conservation plans. We can inspect them. We can kind of offer advice, do a lot of that face to face thing with a grower that the NRCS staff does, but we are not full-time employees. So, that is supposed to be the best of both worlds.

Part of what makes that a successful kind of program, as long as it is promoted to growers, is that a customer farmer to NRCS can work through some of this stuff without having to go to the government to get help. They are still going through that process, but inherently, farmers, at some point, don't want to go sit in a government office to work through conservation issues. That is just the way it is. If they can go to another grower or a private individual and work through some of that, they tend to be a little more open. It is a little bit easier process to get through. And it is a cumbersome process no matter how you go about it. Anything you can do to make it easier is going to really increase the chance that it is successful at the end of the project.

Ms. SCHRIER. I understand that about the government offices. What kind of training did you go through? Was it all kind of in your own experience training? How did you learn and then leverage to help your colleagues?

Mr. MADISON. It is basically your past experience. I had to provide references from growers who I have worked with in the past, work experience. At the time, I had several years working in retail selling fertilizer, selling seed. I had a certified crop advisor certification, that helped, and a certified nutrient management planner in Virginia. All those things kind of go in there together, and somebody reviews it somewhere on the other side of that computer screen and tells you if it is enough. And in my case, it was enough.

Ms. SCHRIER. That is great. Thank you.

I was also struck by your testimony of working in the fields all day long until 9:00 or 10:00 at night tilling, and then if it rained the next day, you lost all of that rich topsoil. And then so I was listening to you, Mr. Cameron, talk about soil health and not tilling. I have a really interesting picture posted in my office of two farms on different sides of a street, one farmed with no-till and the other conventional, and after a flood, the conventional farm is far underwater and the other one has absorbed that moisture. It holds it in periods of drought and rain.

But you are by the Chesapeake Bay and you wanted to avoid runoff there. I am by the Columbia River and Puget Sound. I was just wondering if you could comment on some of the things that you have found have helped protecting your natural waters?

Mr. MADISON. The basics were a really good start. When I say the basics, I mean nutrient management, cover crops, and no-till. In Virginia, they are starting to sound old. Everybody already does that stuff. Nobody wants to talk about it anymore. But I know in other parts of the country, that is not the case. And the reason it sounds old in Virginia is because we all do it because we have all kind of figured out that it works. And there is nothing better than using other farmers as examples. We are all pack animals. If we see somebody else do something, we want to go do it, too, or at least try it.

Ms. SCHRIER. And in my last 16 seconds, do you have any ideas about how to get that to the rest of the country? Because I do think farmers listen to farmers more than they will listen to me.

Mr. MADISON. In Virginia, it was not a very fast process. You had to just keep hammering away on that point. Now we have, through precision ag, we can do case studies a lot better. We can actually put numbers to things. In the past, it was kind of do this, it will work. I promise. Now, we can break it out and I can cover you with spreadsheets and layers of data that prove to you that it worked over a few years. That is going to be important as we go forward with farmers needing to make it on their margins. They will follow the money.

Ms. SCHRIER. Thank you very much, and thank you for what you have done.

The CHAIR. I thank the gentlewoman from Washington State for talking so much about Virginia.

With the first round of questions completed and without objection, we will begin a second round of questions. Members who wish

to be recognized will be recognized for 5 minutes in order of seniority, and I will now recognize myself for 5 minutes.

Mr. Cameron, we touched upon an interesting topic when you mentioned very briefly the almond groves. Precision agriculture technologies do vary significantly by commodity type, and unlike row crops, not all specialty crops are planted annually. And additionally, specialty crops tend to have unique planting, harvesting, packaging processes and production operations.

What role have you seen or what role can precision agriculture play when it comes to other crops beyond row crops?

Mr. CAMERON. I will stick with one of our many, and that would be our processing tomatoes.

We research varieties that we want to grow prior to planting. We look at yield data, university work that has been done, and then we deal with our processor who really tends to dictate our schedule of harvest. But when we look at a crop like that, we use precision irrigation for watering. We do petiole soil tests. We monitor the plant as it grows. We apply the fertilizer that is only what is needed and only the—we have irrigation scheduling. We monitor the inputs very closely.

When we get to harvest, we harvest 24 hours, 7 days a week from early July until October. And when a load of our tomatoes, a 25 ton load of tomatoes heads to a cannery, we get a grade from the California Department of Food and Agriculture that I can access 5 minutes after the load gets to the cannery. It puts it by variety, by field. It will calculate the income from that load. It will show me any deductions that I may have. And like I say, it will give me a yield per field as we move through our different parts of the ranch. The technology is there. For a crop like that, the results help me in determining how to set our harvester as we progress on different varieties. And I guess that takes you to harvest. It is pretty intense, but it is very—really, the information we get instantaneously, but like I said, we either have to have a phone connection or the broadband.

The CHAIR. And if you wouldn't mind just answering a couple questions related to that process?

You said within 5 minutes you are getting information back from the cannery related to those tomatoes. When that is happening early in the season, based on that feedback, are you able to or do you frequently make adjustments to your crop based on what you are hearing back from the cannery?

Mr. CAMERON. Yes, we can make adjustments. We can either, we have electronics on our harvester that will actually put green tomatoes back on the ground. We may have an issue with the harvester. It will show us immediately. From the time it is picked to the time it hits the canner, the grade station, is probably within 2 hours or less. We can make adjustments to our harvester if we can get a hold of our guys. They can access this at 2 o'clock in the morning in the field, provided they have connection.

Yes, it is extremely valuable and we will adjust. Moving forward, we will either slow down harvest or speed up harvest, depending on the quality we see. It is really informative.

The CHAIR. Thank you very much, Mr. Cameron.

Mr. Madison, with your experiences, if you could just talk for a moment about some of the precision ag technology that you employ on your farm, whether your experiences are similar in terms of your ability to adjust relatively quickly, or how it impacts your day-to-day operation in Virginia?

Mr. MADISON. Our biggest assets, as far as precision goes, are yield monitors, they kind of grade us at the end of the year, tell us what we did right, what we did wrong, or tell us if we tried something new, whether or not that worked. All of our GPS technology is somehow tied back to the precision work that we set up at the beginning of the year, whether it is not overlapping seed, not overlapping fertilizer, making sure we are putting everything really exactly where it needs to go.

The big difference in commodity farming, after we get that grade at the end of the year, we don't get to change anything for 6 months. We don't get to change a lot on the go. There are some things maybe in season that we can do when we are making some fertilizer applications here and there, but overall, that is a really minor part of what we have used.

The CHAIR. Thank you very much.

I now recognize Mr. LaMalfa, for 5 minutes.

Mr. LAMALFA. Thank you.

Mr. Cameron, you get the travel award here. As I note each week, it is about an 18 hour round trip here, and so to spend that many hours traveling and taxi rides and hotel rooms and all that stuff, you probably get a grand total of 20 to 25 minutes of testimony time. I would like to throw it to you and see if there is anything you would like to touch on. I would give you a possible topic with water conservation. How about at the macro-level and how our lakes are managed and how much water is running out the delta and how beneficial that would be to capture more of that with more dynamic weather forecasting and reality that they are looking at a possible drought situation or a low rain situation in California, yet they are letting water out of Shasta Dam right now.

So that, and opportunity for groundwater recharge, sigma coming down the pike. What would you say about the bigger picture of water conservation for California?

Mr. CAMERON. Water is always the number one issue in California. It is either the lack of or too much at the wrong time. We have an old infrastructure in place that needs to be updated. We need conveyance to move water to areas where it is needed. I mean, it would be great if it fell uniformly throughout the state, but it doesn't. It tends to fall as snowfall in the northern part of the state, and we have a difficult time moving it through the delta because of endangered species law that precludes some of the movement.

You are right. We get a tremendous amount of water that goes out of the delta into the ocean. We figured out a long time ago that it was—we saw declining water tables in our region and decided to do something about it, and that was to take flood water and move it on farm and start recharging groundwater.

But like I say, the projects like that are expensive. We got help from a grant from the Department of Water Resources in California. It was supposed to be a \$5 million grant plus a \$2 million

match on our side. Because of all the reporting, the environmental regulations that we had and hoops we had to jump through and agreements we had to get in place, it took us 6 years from the time we got the grant until the time we started construction, which was last year. We hope to have it finished this year, but the price in the meantime went up to about \$11 to \$12 million. We know that these projects are costly, but the growers in California understand without it the prediction is we are going to be seeing anywhere from ½ million to 1 million acres of farmland in central California being idled in the next 20 years with sustainable groundwater management.

We need real solutions. We have a treasure. We have a national treasure in the San Joaquin Valley, and to see it sit idle because of a lack of water is wrong.

Mr. LAMALFA. Yes. We have the opportunity to raise Shasta Dam 18', 600,000 more acre feet on those years that it would fill, and then the opportunity right now to be filling San Luis Reservoir. Do you draw from San Luis?

Mr. CAMERON. I do on one farm, but the majority is pumped groundwater, which is really under the microscope right now.

Mr. LAMALFA. Does anybody disagree that the groundwater recharge and the infrastructure needed for that, does anybody disagree with those projects? Are there environmental groups that are against that?

Mr. CAMERON. From what we have seen, we have a great amount of support. Although I did find one person at a meeting that was outspoken that for whatever reason didn't think that was a good idea. We understand that, with groundwater recharge on farmland, you have to have a different set of best practices. You are going to have to farm differently, because we don't want to push nitrates into the groundwater, or any pesticides that we may have applied. We are doing a base study with Department of Pesticide Regulation currently at the state level, monitoring our water as a baseline before we really get into this heavily, and we are also doing ground radar with Stanford and UC Davis and Corring. We are going to be a test bed for groundwater recharge.

We started the, like I say, the project in 2011 and we are the innovators to bring this in. It has now got a life of its own in California.

Mr. LAMALFA. Yes. I know the Bureau is looking at rejiggering things a little bit on saving water in the reservoirs and using more dynamic weather forecasting on how we can more aggressively keep our reservoirs full and make more of this possible.

Mr. CAMERON. We would like to see a lot better long-term forecasting as well for agriculture. We have been neglected, as we have in other areas. Services have been cut back.

Mr. LAMALFA. Well, we are working on it both ends. I appreciate your time and travel here, and to all of our panelists, thank you.

I will yield back. Thank you, Madam Chair.

The CHAIR. Thank you.

I now recognize the gentlewoman from Washington State, for 5 minutes.

Ms. SCHRIER. Thank you, Madam Chair. I did have a couple more questions.

Dr. Karsten, Washington State University is not in my district, but it is close to my district. And so, there is a phenomenal partnership between WSU and Agricultural Research Service and our farmers. And so, Washington State University's Center for Precision and Automated Agriculture Systems hosted an ag technology day last summer to look at automation and specialty crops. Experts from WSU, Washington State Department of Labor, Microsoft Farm Beats, and ASI robots explored the theme of automation and specialty crop production. I specifically wanted to draw attention to the amazing work that Microsoft Farm Beats is doing in Washington State. It is an end to end AI and IOTC system for agriculture that gathers data from sensors, cameras, drones, robots also to produce real actionable insights for farmers, and it can extend internet coverage, provided there is some somewhere near the farm, to the farm and it is resilient towards weather and power outages.

I was wondering if you had similar partnerships? In Washington State, the natural one is with Microsoft, and we saw something similar in Israel where they had robots that were taking cameras and figuring out what was going on with plants there. What are some of the partnerships you have found?

Dr. KARSTEN. First, I would say that I actually don't work in specialty crops. I am aware of some of the work that my colleagues are doing to improve these and develop these technologies such as using cameras and imaging and water sensors and other sensors in orchards and specialty crops.

The work that I know is work that is being done by faculty with growers and extension, and some of it is free online. Well, some of it, I am sorry, the pest management data, for instance, so they can monitor pests are online and free. I am not aware of how they are working with companies in that area. That is in another production system.

But my understanding is that that is a great opportunity, that they often do take advantage of in partnerships, because we can have more impact and we can benefit from understanding how we can improve those technologies, make them more cost-effective, and help our students learn how to use them and extension educators also.

Ms. SCHRIER. It has been incredibly helpful for farmers, because they can look at microclimates and figure out where on their field really needs more water and where it doesn't, similarly with micronutrients.

I also just had a curiosity question, Mr. Cameron, since I have a tiny bit of time left. Water is so scarce in California. It is also scarce in parts of Washington State, so this is becoming a really common issue.

I want to learn from California. How much attention has gone to choosing which crops to grow? Which ones require the least water and create the most food, for example? Has any attention gone to that topic?

Mr. CAMERON. Onto which crops use more water or less water?

Ms. SCHRIER. I mean, I am sure I know the information, but kind of prioritizing how much yield you could get for how little water, and figure out which ones to grow.

Mr. CAMERON. Well, we know almonds made the headlines during our drought, and there have been several studies that have showed that actually deficit irrigation can still produce a very profitable crop and reduce the water footprint. We know that is the number one crop in California now with 1.4 million acres and continuing to increase. And you will see more of that as sustainable groundwater management is implemented. The water is going to go to the higher dollar crops. We know that. And those that don't make the cut will be gone.

I think that, when you talk about reducing water, California has gone to micro-irrigation for the majority of their crops. Unless you have plentiful surface water, there is a big distinction between the two, and that is what has driven a lot of the technology in California, the high costs or the unavailability of water, to where we have become extremely efficient in the water usage on the crops we grow.

Maybe we can do more.

Ms. SCHRIER. Thank you. It's super interesting. We even found out that in Israel, they have found that brackish water makes their watermelons taste better, and so they have been able to use that.

Thank you very much.

Mr. CAMERON. There has been brackish water being filtered and used in agriculture, yes, and blended.

Ms. SCHRIER. Thank you. That is super interesting.

The CHAIR. Thank you all for your testimony and your candor in answering our questions today.

What I am hearing is really remarkable, and I hope others are hearing it, too. Farmers are at the forefront of adopting revolutionary new technologies that will enable us to meet our shared goal of food security, while at the same time carefully and strategically managing environmental impacts.

I would like to take a moment to put the speed of this remarkable technological march into perspective. If the average age of the U.S. farmer is almost 60 years old, many of our farmers grew up farming with their parents, managing their crops using time tested tools of intuition and instinct, and many of those men and women farming today with their kids have the ability to generate a multi-dimensional digital model of their operations with extensive data on everything from crop health to input use to market intelligence, all while auto-steer drives their tractor with the aid of GPS, and evidently, farmers and growers can watch movies while doing so. Perhaps most astounding is that all of this innovation has come in the span of a few decades in a generation, and rivaling the technological advances of any other industry.

I hope you all are as proud of this American ingenuity as I am, and as Members of this Committee are, and I hope when we walk out of this hearing, we will have greater clarity not just about the conservation benefits of precision ag, but also about what is indeed needed to realize these benefits at scale. We have spoken a lot today about the need for broadband internet and the impact that lack of internet infrastructure has on the ability of farmers and producers to use these incredible technologies. And while the picture that I have described is true for many farmers, those without that access to broadband face financial uncertainty, as they are not

able to implement the technologies that in many cases they have already paid for.

As Representatives for our constituents and Members of this Committee, we have a responsibility to take up the challenge to improve the outcomes, not just on the fields and across ecosystems, but for our rural communities, the communities that are working tirelessly to put the food on the table that we all eat.

I thank you all for joining us today, and I give a special thanks to agriculture and conservation expert Dustin Madison, who joined us from Louisa County in Virginia. And with that, I thank you all for your time. I thank you for joining us, and I now close this hearing of the Conservation and Forestry Subcommittee.

Under the Rules of the Committee, the record of today's hearing will remain open for 10 calendar days to receive additional material and supplementary written responses from the witnesses to any question posed by a Member.

This hearing of the Subcommittee on Conservation and Forestry is now adjourned.

[Whereupon, at 3:30 p.m., the Subcommittee was adjourned.]

[Material submitted for inclusion in the record follows:]

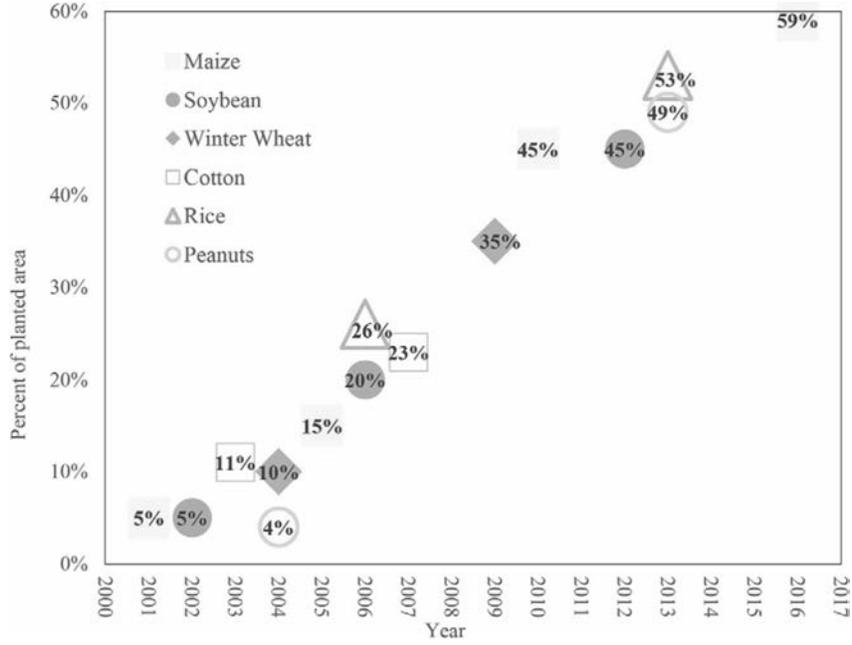
SUPPLEMENTARY MATERIAL SUBMITTED BY HEATHER D. KARSTEN, PH.D., ASSOCIATE PROFESSOR, CROP PRODUCTION/ECOLOGY, DEPARTMENT OF PLANT SCIENCE, COLLEGE OF AGRICULTURAL SCIENCES, PENNSYLVANIA STATE UNIVERSITY

Chair Spanberger, [Ranking Member] LaMalfa, and distinguished Members of the Committee, thank you for this opportunity to discuss the conservation benefits of precision agriculture, some examples of precision agriculture, barriers to adoption and the role of the land-grant universities. Precision agriculture technologies and their potential applications for conservation benefits are diverse and significant. Precision agriculture technologies utilize spatial and temporal agroecosystem and hydrologic data in geographic information systems (GIS) software that can be linked to automate equipment navigation of agricultural operations such as planting and spraying operations via robotic technologies. In addition, real-time data from sensing technologies such as in-field sensors, remote sensing or thermal imaging can be integrated with GIS data and historical management data in decision support tools (DST) and decision support systems (DSS) (Drohan, *et al.*, 2019). Agroecological and hydrologic computer simulation models are utilized in decision support systems along with other factors such as weather forecasts and/or economic data to provide farmers and land managers with site-specific management options that can result in reduced environmental impact and economic costs of agricultural activities. For instance, integrating maps of soil characteristics such as fertility, slope and drainage; crop yields, and pest infestations along with weather forecasts can enable managers identify zones for specific application rates of seeds, nutrients, pesticides and irrigation water at the optimal time with variable rate technologies (VRT). Similarly, livestock managers can utilize precision feeding to develop nutritionally balanced cost-effective rations that meet the metabolic needs of livestock at various life stages without excess nutrients.

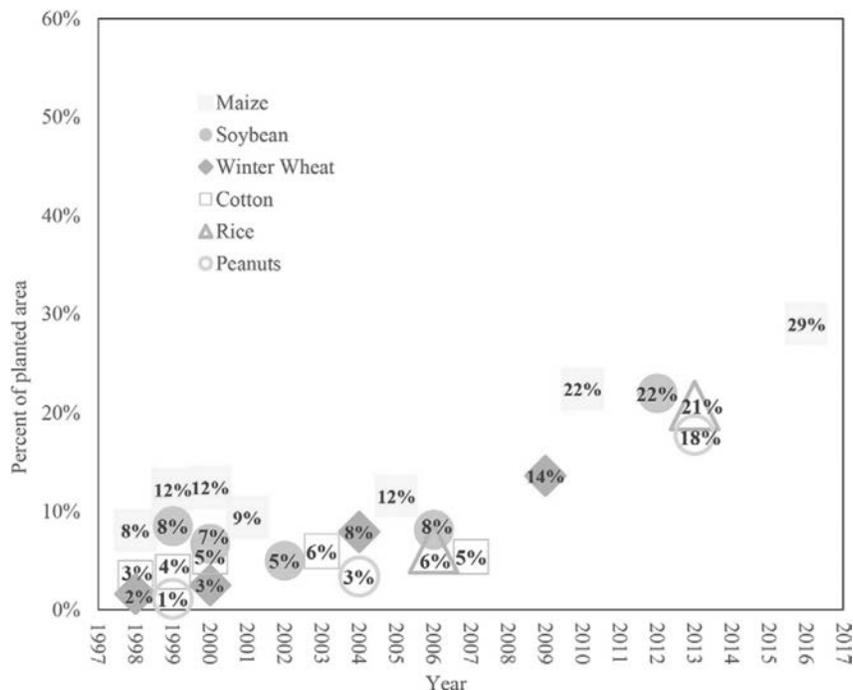
Adoption Barriers

A recent analysis of multiple surveys on the adoption of precision agriculture since the 1990s, suggested some rapid adoption as well as barriers to adoption. Adoption of global navigation satellite systems (GNSS) with auto guidance and technologies such as sprayer control and planter row or section automatic shutoffs has been relatively rapid for agronomic crops (see *Figure 3* from Lowenberg-DeBoer and Erickson, 2019), while adoption of variable rate technology (VRT) has been relatively slow and “rarely exceeds 20% of farms” (see *Fig. 4* from Lowenberg-DeBoer and Erickson, 2019). The study’s authors summarized three hypotheses for the slow rate of adoption that were frequently described in the cited surveys: i. the cost of VRT was too high, ii. “more reliable VRT decision rules” were needed, particularly for nitrogen; and iii. farmers weren’t convinced VRT would increase their profits (Lowenberg-DeBoer and Erickson, 2019).

Fig. 3.



Planted area by crop in the United States where Global Navigation Satellite Systems (GNSS) auto guidance was used, 2000 to 2016.

Fig. 4.

Planted area by crop in the United States where variable rate technology (VRT) was used for any purpose, 1998 to 2016.

Figures 3 and 4 from Lowenberg-DeBoer J. and B. Erickson. 2019. *Setting the Record Straight on Precision Agriculture Adoption*. AGRONOMY JOURNAL 2019 111: 1535–1551, doi:10.2134/agronj2018.08.0535.

Additional adoption barriers that others describe include the need for technical expertise to install and operate precision technologies, the fact that new equipment is often needed to be compatible with the new technologies, access to broadband, and other factors that are summarized and shown below in *Table 1* from Wolfe and Richard (2017).

Table 1—Overview of barriers to the adoption of pro-environmental technological innovations (general and agriculture specific) based on literature review (from Long, *et al.* [31]. Sources are listed in [31] and not repeated here.

Barrier	Sources
Economic	(Bogdanski, 2012; Brunke, <i>et al.</i> , 2014; Cullen, <i>et al.</i> , 2013; del Río Gonzalez, 2005; Faber and Hoppe, 2013; Hoffman and Henn, 2008; Luken and Van Rompaey, 2008; Luthra, <i>et al.</i> , 2014; McCarthy, <i>et al.</i> , 2011; Montalvo, 2008)
	High initial investments
	Poor access to capital
	Hidden costs
	Competing financial priorities
	Long pay-back periods (ROI)
	Switching costs/existence of installed base
	High implementation costs (actual and perceived)
	Uncertain returns and results
	Temporal asymmetry between costs and benefits
	Over discounting the future

Table 1—Overview of barriers to the adoption of pro-environmental technological innovations (general and agriculture specific) based on literature review (from Long, *et al.* [31]. Sources are listed in [31] and not repeated here.—Continued

Barrier		Sources
Institutional/regulatory	Low institutional support Use of overly scientific language (Jargon) Farmer's knowledge not considered in R&D Lack of regulatory framework Prohibitively prescriptive standards	(Bogdanski, 2012; Eidt, <i>et al.</i> , 2012; Luthra, <i>et al.</i> , 2014; Montalvo, 2008)
Behavioral/psychological	Lack of management support/awareness Conflict with traditional methods Overly complex technologies Results/effects of technology difficult to observe Farmer's beliefs and opinions Low trust of advisers or consultants/lack of acceptance Irrational behavior Negative presumed assumptions	(Brunke, <i>et al.</i> , 2014; Eidt, <i>et al.</i> , 2012; Hoffman and Henn, 2008; Johnson, 2010; Ratten and Ratten, 2007; Sneddon, <i>et al.</i> , 2011; Vishwanath, 2009; Wheeler, 2008)
Organizational	Lack required competencies/skills Poor readiness Poor information Inability to assess technologies Overly short-term/perverse rewards Organizational inertia/habitual routines	(Brunke, <i>et al.</i> , 2014; Faber and Hoppe, 2013; Johnson, 2010; Luken and Van Rompaey, 2008; Luthra, <i>et al.</i> , 2014; Montalvo, 2008)
Consumers/market	Poor information Lack market attractiveness/do not align to preferences Uncertainty Consumers/farmers level of motivation Market uncertainty	(Bogdanski, 2012; Bohnsack, <i>et al.</i> , 2014; Brunke, <i>et al.</i> , 2014; del Río Gonzalez, 2005; Johnson, 2010; Luthra, <i>et al.</i> , 2014)
Social	Social/peer pressures	(Montalvo, 2008)

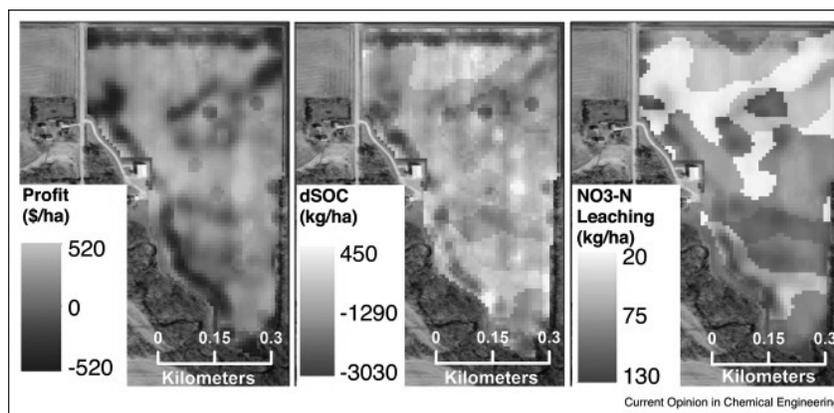
For farmers with limited capital facing small profit margins, the capital investment required for new precision agriculture technologies and the technical expertise required can be significant barriers. Land-grant university researchers and educators such as my colleagues at Penn State are currently working with farmers, the national laboratories (ex. ARS) and government agencies (ex. NRCS); as well as private-sector partners to develop low-cost technologies, open-source or free software, and decision support tools and systems that can be operated on smartphones or personal computers. Land grants are also well-positioned to conduct objective, trustworthy assessments of precision technologies, while training students, educators, and the workforce to develop, improve and assist in the use of precision technologies.

Decision support systems can empower farmers and producers to fine-tune their management practices when coupled with economic incentive policies that promote adoption (Drohan, *et al.*, 2019). Support for on-farm assessment and peer-to-peer learning also appear to facilitate adoption of precision conservation technologies. A final report from a Penn State interdisciplinary research and extension project provides an example of what a DSS can provide. “There is no one production practice that will make or break a herd’s profitability Combining financial metrics with decision-making on cropping and feeding practices is still a challenge for both producers and consultants. . . . The bottleneck is how cropping strategies and animal performance influence the whole farm system and the impact to the bottom line. Unless nutritionists and crop consultants work with financials on a routine basis, it is unlikely they will embrace this aspect when working with their clientele.” (Ishler, *et al.*, 2019).

Some examples of precision conservation technologies and DSS that offer promise of adoption are briefly described here. Decision support systems (DSS) that produce farm profit maps can enable farmers and land managers to identify opportunities to increase their profits while reducing their environmental impact. Agroecosystem DSS can identify field zones that are consistently low profit or unprofitable enabling land-managers to consider alternative managements. Low profit or very unprofitable

zones are often zones of significant soil and/or nutrient losses associated with soil and landscape factors (Delgado and Bausch, 2005; Muth, 2014) as illustrated in *Figure 1* from Wolfe and Richard, 2017. Such landscape features may also make zones particularly vulnerable to extreme weather events such as drought or flooding. For instance, a 2017 NRCS funded study of over 200,000 acres from nearly 3800 fields on 136 farms in a dozen states found that (a) more than 90% of fields included zones that were losing money due to some combination of risks, and (b) over 50% of the unprofitable acres were also acres with substantial environmental concerns (Thomas Richard, personal communication 2019).

Figure 1



Subfield economic analysis demonstrates high variability in profitability, with a significant fraction of currently farmed acres highly unprofitable for annual crops. Left panel: profit in $\$ \text{ha}^{-1}$; center panel: change in Soil Organic Carbon in kg ha^{-1} , and right panel, nitrate ($\text{NO}_3\text{-N}$) leaching in kg ha^{-1} .

Figure 1 from Wolfe, M.L. and T. L. Richard. 2017. *21st Century Engineering for On-Farm Food-Energy-Water Systems*. CURRENT OPINION IN CHEMICAL ENGINEERING <https://doi.org/10.1016/j.coche.2017.10.005>.

Decision support tools that integrate landscape characteristics, with crop management history and yields; agroecosystem models, and economic analyses and sensor data can help farmers identify practices to reduce their production costs in low-profit zones and/or increase their cropping system resilience (*Fig. 2*. Wolfe and Richard, 2017).

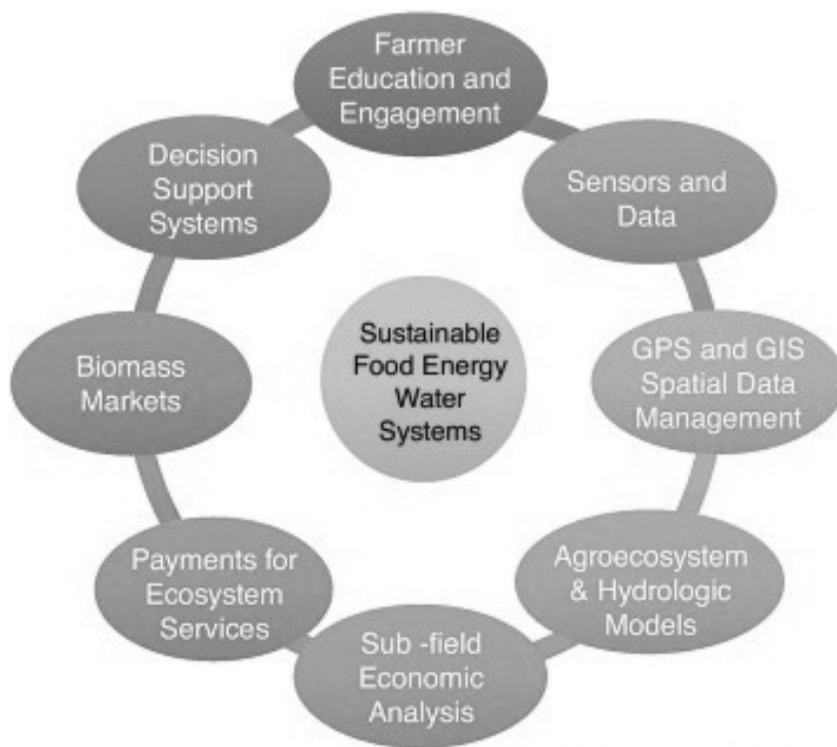
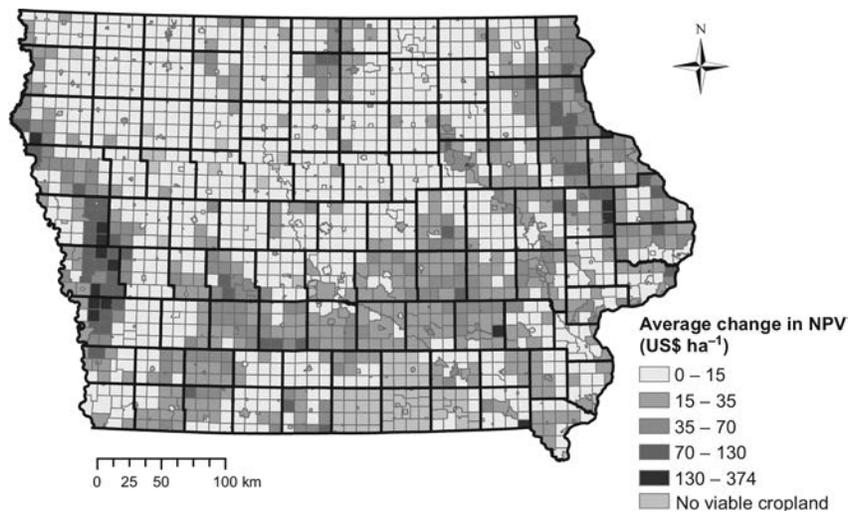
Figure 2**Current Opinion in Chemical Engineering**

Figure 2 from Wolfe and Richard, 2017. Sustainable food-energy-water systems are enabled by an expanded precision agriculture toolset that includes economic analysis, payments for ecosystem services, and biomass markets, all managed through decision support systems that go beyond inputs and single crop management to innovative cropping system and landscape design.

Alternative management scenarios may include reducing fertilizer inputs and adopting conservation farming practices (Delgado and Bausch, 2005, Muth, 2014, Capmourteres, *et al.*, 2018; Amin, *et al.*, 2019). In zones where annual cropping is unprofitable, the establishment of perennial plants for bioenergy, forage or other markets offers a viable economic alternative (Wolfe and Richard, 2017) such as shown below in *Figure 6* from Brandes, *et al.*, (2018).

Fig. 6



Average annualized changes in net present value (Δ NPV) when economically under-performing cropland is converted from corn/soybean to switchgrass. Values (in U.S.\$ ha⁻¹) are calculated by dividing the sum of annualized Δ NPV by the total corn/soybean cropland area per township. Gray areas represent townships without any cropland economically viable in switchgrass. The results assume USDA projected (medium) grain prices, medium switchgrass price, medium switchgrass yield, and that all land is owned by the farm operator.

Figure 6 from Brandes, E., A., Plastina, and E. Heaton. 2018. *Where can switchgrass production be more profitable than corn and soybean? An integrated, sub-field assessment in Iowa, USA*. GLOBAL CHANGE BIOLOGY BIOENERGY. 10, 473–488, doi: 10.1111/gcbb.12516.

Planting perennials (Capmourteres, *et al.*, 2018) and removing zones from production can also provide multiple conservation benefits for a relatively low cost. In Iowa, compared to similar watersheds that were 100% row-cropped, planting only 10% of a corn-soybean field to prairie strips reduced sediment loss by 95%, phosphorus and nitrogen losses by 90% and 85%, respectively; while also providing habitat for biodiversity, such as grassland birds and pollinators (Liebman and Schulte, 2015).

Decision support systems (DSS) such as CropSyst (Stockle, *et al.*, 2014) or SWAT that integrate agroecosystem features and hydrological models, or climate projections have also been employed to evaluate various management scenarios such as nutrient management or projected climate change impacts and mitigation approaches (Stockle, *et al.*, 2014; Amin, *et al.*, 2019). Land-grants researchers working with USDA ARS, other national laboratories, and “big-data” have developed multiple DST and DSS to provide growers with information to strategically reduce soil phosphorus and comply with nutrient regulations (Drohan, *et al.*, 2019; Amin, *et al.*, 2019); and to reduce production costs, pesticide applications, and crop damage from insect pests and disease infestation through free online real-time pest monitoring websites. A few examples of these free online precision technologies and additional precision DST and DSS that were developed or are under development at Penn State are described below.

In conclusion, the strength of land-grants and Penn State is in our ability to bring together diverse faculty and extension educators to work with farmers, USDA partners, national laboratories, and the private-sector. With evidence of multiple opportunities for precision agriculture and conservation technologies to provide environmental and economic benefits, we are advancing their development, application, and our educational activities to support farmers and land managers in the conservation of our agricultural and natural resources.

I thank the Committee for this opportunity to provide testimony and to address your questions. A brief description of some additional precision agriculture tech-

nologies that were developed or are under development at Penn State are described below.

- PestWatch is a long-term monitoring program developed at Penn State that has expanded from 200+ stations in the East Coast, to 700+ stations nationwide (mostly MS river and east). PestWatch provides guidance for individual producers on the extent and location of various corn pests in the agricultural regions of the eastern United States. The unique use of climate and weather data within PestWatch has led to additional tools for battling brown-marmorated stinkbugs, slugs, and the newly critical insect pest, Spotted Lantern Fly. The core tool is located at: <http://www.pestwatch.psu.edu/>.
- Wheat Fusarium Headblight is the leading plant pathogen of wheat in the United States and abroad. Penn State, along with collaborators at Kansas State and across the Wheat Belt, has developed the Wheat Fusarium Head Blight Prediction Center to provide farmers with actionable information on this crop pathogen. The Prediction Center, and its associated map tool, has been in continuous use and supported by the USDA Wheat and Barley Scab initiative for more than 19 years. This tool provides daily guidance for farmers across the entire U.S. Wheat growing region. The tool is located at: <http://www.wheatscab.psu.edu/>.
- Reducing the risk of crop damage by using drones, to monitor air temperatures on nights when there is frost and sending commands to ground robots with heaters mounted on them so growers can target only those areas most at risk are protected, while minimizing energy use.
- Precision, automated irrigation systems (drip irrigation) for tree fruit and vegetable crops that operate on soil moisture sensors and IoT (internet of things) system. The use of precision and automated irrigation systems can maximum the water use efficiency (apply water at right time and right amount), reduce the impact to the environment caused by the nutrient leaking, and save energy and costs.

Predictive Models

- Every winter, 30–40% of managed honey bee colonies in the U.S. die. This is an enormous economic cost to beekeepers, and threatens our food security since 75% of our major food crops benefit from the pollination services of honey bees and other insects. Using data provided by Pennsylvania beekeepers, a team at Penn State and the USDA–ARS has developed models which can predict winter survival rates with 70% accuracy. These complex models integrate data on climate, landscape quality, and beekeeper management practices. We have developed an online portal, called Beescape, which allows individuals to evaluate the quality of their landscapes for supporting bee health. We are current integrating our predictive models into Beescape so that beekeepers can understand the risk to their honey bees in their locations, and take steps to improve bee survival. Beescape can easily be adapted to provide information on other measures of honey bee and wild bee health, including honey production and biodiversity. This program is funded by USDA NIFA and the Foundation for Food and Agricultural Research.
- In soybeans, we have been working from an extensive dataset (ten states, 3 years, just under 5,400 responses) to determine under what conditions foliar fungicides would be warranted. We have built a global models for (1) management factors, and (2) management in combination with environmental and physiological parameters, all with the goal to understand under which environmental domains might a foliar fungicide show a positive weight (*i.e.*, influence positively the observed yield).

Remote Sensing and Decision Support Technologies

- We are actively engaged in applied research to use a combination of sUAS-based (drone-based) sensors, including multispectral cameras and LiDAR sensors in both airborne and terrestrial modes, to develop, test, and apply new techniques to measure forest ecosystem attributes at scales ranging from individual trees to forest stands. We combine emerging low-cost reality capture sensors with a seamless user interface, through custom software applications, to foster automation in the forest industry. We aim to transform the current rudimentary and labor-intensive mensuration methodology employed by foresters through the what we've named the "RealForests" system. RealForests fuses low-cost remote sensing hardware and intuitive software design to allow for rapid data collection of key forest attributes for forest appraisal and to support management decisions. Easy data collection integrated into existing field procedures

is critical to market entry. Existing algorithms have allowed our team to locate individual tree objects and estimate critical measurements. RealForests will allow the user to add information, such as species identification, that can be linked to objects in the 3D model of the forest created by the system.

References

- Amin, M.G.M., T. Veith, J. Shortle, H.D. Karsten, and P.J.A. Kleinman. 2019. *Addressing the spatial disconnect between national-scale total maximum daily loads and localized land management decisions*. J. ENVIRON. QUAL. doi: 10.2134/jeq2019.03.0120.
- Brandes, E., A., Plastina, and E. Heaton. 2018. *Where can switchgrass production be more profitable than corn and soybean? An integrated, sub-field assessment in Iowa, USA*. GLOBAL CHANGE BIOLOGY BIOENERGY. 10, 473–488. doi:10.1111/gcb.12516.
- Capmourteres, V., J. Adams, A. Berg, E. Fraser, C. Swanton, and M. Anand. 2018. *Precision conservation meets precision agriculture: A case study from southern Ontario*. AGRICULTURAL SYSTEMS. 167: 176–185. <https://doi.org/10.1016/j.agry.2018.09.011>.
- Delgado, J.A. and W.C. Bausch. 2005. *Potential use of precision conservation techniques to reduce nitrate leaching in irrigated crops*. JOURNAL OF SOIL AND WATER CONSERVATION. 60(6): 379–387.
- Drohan, P., M. Bechmann, A. Buda, F. Djodjic, D. Doody, J.M. Duncan, A. Iho, P. Jordan, P.J. Kleinman, R. McDowell, P. Mellander, L.A. Thomas, and P.J.A. Withers, et al. 2019. *A global perspective on phosphorus management decision support in agriculture: Lessons learned and future directions*. JOURNAL OF ENVIRONMENTAL QUALITY. 48: 1218–1233. doi:10.2134/jeq2019.03.0107.
- Ishler, V., R. Goodling, T. Beck. 2019. *The Impact of Corn Silage Harvesting and Feeding Decisions on Income Over Feed Costs*. Part of a Final Research and Extension Education report that was funded by NESARE USDA NIFA. April 11, 2019.
- Liebman, M. and Schulte, L.A., 2015. *Enhancing agroecosystem performance and resilience through increased diversification of landscapes and cropping systems*. ELEM. SCI. ANTH., 3, p. 000041. DOI: <http://doi.org/10.12952/journal.elementa.000041>.
- Lowenberg-DeBoer J. and B. Erickson. 2019. *Setting the Record Straight on Precision Agriculture Adoption*. AGRONOMY JOURNAL 2019 111: 1535–1551, doi:10.2134/agron2018.08.0535.
- Muth, D. 2014. *Profitability versus environmental performance: Are they competing?* JOURNAL OF SOIL AND WATER CONSERVATION. 69(6). 203A–206A. doi: 10.2489/jswc.69.203A.
- Richard, Thomas. Personal communication. Oct. 20, 2019. Professor of Agricultural and Biological Engineering, The Pennsylvania State University. <https://abe.psu.edu/directory/Hr20>.
- Stockle, C.O., A.R. Kemanian, R.L. Nelson, J.C. Adam, R. Sommer, and B. Carlson. 2014. *CropSyst model evolution: From field to regional to global scales and from research to decision support systems*. ENVIRONMENTAL MODELLING & SOFTWARE. <http://dx.doi.org/10.1016/j.envsoft.2014.09.006>.
- Wolfe, M.L. and T.L. Richard. 2017. *21st Century Engineering for On-Farm Food-Energy-Water Systems*. CURRENT OPINION IN CHEMICAL ENGINEERING. <https://doi.org/10.1016/j.coche.2017.10.005>.

