INCREASING RESILIENCY, MITIGATING RISK: EXAMINING THE RESEARCH AND EXTENSION NEEDS OF PRODUCERS

HEARING

BEFORE THE

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BIOTECHNOLOGY, HORTICULTURE, AND RESEARCH

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INCREASING RESILIENCY, MITIGATING RISK: EXAMINING THE RESEARCH AND EXTENSION NEEDS OF PRODUCERS

WEDNESDAY, JUNE 12, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON BIOTECHNOLOGY, HORTICULTURE, AND RESEARCH,
COMMITTEE ON AGRICULTURE,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:00 a.m., in Room 1300 of the Longworth House Office Building, Hon. Stacey E. Plaskett [Chair of the Subcommittee] presiding.

Members present: Representatives Plaskett, Delgado, Cox, Harder, Brindisi, Van Drew, Schrier, Pingree, Panetta, Peterson (*ex officio*), Dunn, Thompson, Yoho, and Baird.

Staff present: Kellie Adesina, Malikha Daniels, Brandon Honeycutt, Keith Jones, Ricki Schroeder, Patricia Straughn, Jeremy Witte, Dana Sandman, and Jennifer Yezak.

OPENING STATEMENT OF HON. STACEY E. PLASKETT, A DELEGATE IN CONGRESS FROM VIRGIN ISLANDS

The CHAIR. Good morning, everyone. This hearing of the Subcommittee on Biotechnology, Horticulture, and Research entitled, *Increasing Resiliency, Mitigating Risk: Examining the Research and Extension Needs of Producers,* will come to order.

I want to thank you all for being with us this morning as we examine the research and extension needs for producers.

Looking back on the past year, we have seen intense flooding in the Midwest, hurricanes in the Southeast, and wildfires out West.

Just this week, USDA released a Crop Progress Report detailing that 60 percent of soybeans have been planted in surveyed states, compared to 88 percent historical planting average.

As we speak, flooding is keeping farmers out of the field. These disasters, driven by an increasingly variable climate, pose serious threats to the domestic agricultural industry and the rural communities depending on this sector.

Unfortunately, I have seen this firsthand in the Virgin Islands. In 2015, the territory suffered a serious drought. In 2017, we were hit by two major hurricanes. Now, once again, back in drought. Recovery continues to be an ongoing process. My farmers and ranchers need tools that not only help them survive but thrive in the face of a changing climate.

These examples show that farmers and ranchers throughout the country are constantly forced to deal with variables that are outside their control.

To remain economically viable and to protect already slim margins, producers seek to create resilient operations by mitigating risk when possible. Advancements in technology and management practices are made possible by robust agriculture research efforts, a topic that is squarely within the jurisdiction of this Subcommittee.

This Committee recognizes the value of investment in public research. In the 2018 Farm Bill, our Committee supported increased funding for programs like the Specialty Crop Research Initiative and the Organic Agriculture Research and Extension Initiative. I strongly supported these increased investments, but we cannot become complacent.

As detailed in a report by the Economic Research Service, the Chinese Government increased spending on agricultural research nearly eight fold between 1990 and 2013. Their spending on public agricultural research surpassed ours in 2008. Ten years later we continue to fall behind.

If we want our agricultural sector to remain competitive, particularly when operating in an increasingly variable climate, we must bolster the resources available to producers.

According to the 2017 Census of Agriculture, there are over 396 million acres farmed in the United States. That is a great number. The farmers and ranchers tending these acres are on the frontlines of a changing climate.

As we seek to develop mitigation and adaptation strategies aimed at combating climate change, farmers and agricultural researchers must have a seat at the table. Their understanding of working the land is vital, and their voices must be heard. Farmers and ranchers are an integral partner in the fight against climate change.

To show that farmers have always been climate focused, I have here, if you can believe this, a 1941 Yearbook of Agriculture from the USDA. It is entitled, *Climate and Man.* One line from the foreword that still rings true today is this, "The first step in increasing knowledge is to have a healthy awareness of what we do not know." Though farmers have always been acutely aware of climate, their ability to respond to shifts in the climate are changing.

So that is why we are here today, to hear directly from the stakeholder community on the research and extension needs of farmers as they seek to increase resiliency and mitigate risk.

I look forward to hearing from our witnesses, and I thank them for taking time out of their schedules to engage with us on this critically important topic.

I would like to thank the witnesses for being here today, and I look forward to receiving their testimony.

[The prepared statement of Ms. Plaskett follows:]

Prepared Statement of Hon. Stacey E. Plaskett, a Delegate in Congress from Virgin Islands

Thank you for joining us today as we examine the research and extension needs of producers. Looking back on the past year, we've seen intense flooding in the Midwest, hurricanes in the Southeast, and wildfires out West. Just this week, USDA released a Crop Progress Report detailing that 60% of soybeans have been planted in surveyed states compared to an 88% historical planting average. As we speak, flooding is keeping farmers out of the field.

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The CHAIR. I now yield to the distinguished Ranking Member of the Subcommittee, the gentleman from Florida, Mr. Dunn.

OPENING STATEMENT OF HON. NEAL P. DUNN, A REPRESENTATIVE IN CONGRESS FROM FLORIDA

Mr. DUNN. Thank you very much, Madam Chair.

Farmers and ranchers are some of the most resilient people that I know, and thanks to our agricultural research and extension system, they are at the forefront of innovation and productivity.

As we look forward, there are always new threats developing, and producers are going to need new tools in order to adapt to changing conditions.

Congress recognized the need for research all the way back in 1862 with the passage of the Morrill Act which created the land-grant university system.

Since then, Congress has provided additional investments in American agricultural research and extension, most recently with the passage of the 2018 Farm Bill.

The livelihoods of farmers, ranchers, foresters, and consumers continue to depend on innovation, and today's challenges are no different than the past.

In the past 2 years, Florida's producers and foresters saw devastating losses from hurricanes, and the citrus industry has been nearly wiped out by citrus greening disease. We are seeing more subtle, yet perhaps even more consequential threats developing, including aggressive pest and disease pressures which will undoubtedly have an impact on food production and availability.

Climate policies like the Green New Deal have consumed the headlines from Congress, often blaming the agricultural sector as the problem. I could not disagree more. I wholeheartedly believe that innovation in American agriculture is part of the solution.

We know that the U.S. agriculture uses a tiny percentage of the energy consumed in the U.S., but the changes proposed in the Green New Deal would have significant implications for the ability of U.S. agriculture to continue to meet the demand for fresh, safe, and affordable food both in the U.S. and abroad.

In contrast, Congress chose a better solution passed in the 2018 Farm Bill, which is arguably the greenest farm bill ever.

In addition to significant investment in research, the farm bill programs protect farm and forest lands and assist producers in voluntary practices that sequester carbon, reduce pollution, and greenhouse gas submissions. They preserve farmland and they improve the energy efficiency of farming practices, all while providing America with abundant and affordable food and fiber.

I would like to call out President Trump for his leadership on this important issue with the signing of yesterday's agricultural biotechnology Executive Order. This Administration is now on a path to eliminating unnecessary regulatory hurdles, while creating opportunity for additional investment in some of the innovative tools we are going to discuss here today.

I look forward to watching the Environmental Protection Agency and the Food and Drug Administration follow the USDA's lead.

I would like to thank each of the witnesses for taking time to have this important dialogue with us, and I look forward to a productive discussion.

And, Madam Chair, I yield back.

The CHAIR. Thank you.

I would note for the record, the presence of the Chairman of our full Committee, Mr. Collin Peterson, who is here with us. Thank you for your presence in this Subcommittee hearing.

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

I would like to welcome all of our witnesses and thank you for being with us here today.

At this time I will introduce our first witness, Dr. David Wolfe. Dr. Wolfe is a Professor of Plant and Soil Ecology at Cornell University in Ithaca, New York. Thank you for being with us.

The second witness is my own constituent, Dr. Robert Godfrey. Dr. Godfrey is the Director of the Agricultural Experiment Station at the University of the Virgin Islands, where he is primarily on the St. Croix campus. Thank you so much for being with us.

The third witness we will hear from, Ms. Brise Tencer, who will be introduced by Congressman Panetta.

Mr. PANETTA. Thank you, Madam Chair, for this opportunity. Ranking Member Dunn and Mr. Chairman, of course, thank you for this opportunity.

It is a real pleasure to introduce one of my good friends and a staunch—and we are so fortunate to have her—advocate, Ms. Brise Tencer, the Executive Director of the Organic Farming Research Foundation, located in Santa Cruz, California on the Central Coast.

Brise brings 20 years of leadership experience on organic food policy, farming, and research issues to OFRF.

She has been a strong, dependable resource and advocate for the organic producers in my district. And let me tell you, historically, as many of you know, especially Brise, it is a district that has been dominated by conventional farming. However, because Brise has spoken up, has spoken out, and continues to speak for our organic industry and our organic farmers, her voice is heard across this country, and that is why organic farming and what the benefits it does for our farmers across this country is heard loud and clear.

So, let me just take this time to introduce to you, Brise, and thank you for being here.

The CHAIR. Thank you.

Mr. PANETTA. I yield back. Thank you.

The CHAIR. I will turn to Congresswoman Schrier to introduce out fourth witness, Mr. Sam Godwin.

Ms. SCHRIER. Good morning. Thank you, Chair.

I am so pleased to welcome Mr. Sam Godwin to testify this morning.

He operates a family organic farm of 300 acres, growing apples, pears, and cherries, true Washingtonian, with his wife, Gwynn and oldest daughter in Tonasket, Washington.

Mr. Godwin received his undergraduate degree from Washington State University, and then Masters from Seattle U.

Prior to his career in agriculture, he worked at the Boeing Company. He currently serves on the Washington State Tree Fruit Association's Board of Directors.

I am excited to hear from you this morning and hear your thoughts about how low- and no-till farming, regenerative farming, crop rotation, and carbon sequestration can really show us that farmers could literally save our planet.

Thank you.

The CHAIR. Thank you.

And I also welcome Dr. Fred Gmitter. Is that the correct way?

Dr. GMITTER. Yes.

The CHAIR. Okay. And he will be introduced by the Ranking Member Dunn.

Mr. DUNN. Thank you, Madam Chair and Chairman Peterson.

It is my honor to introduce a fellow Floridian, Dr. Fred Gmitter.

He is a Professor of Citrus Genetics at the University of Florida Citrus Research and Education Center in Lake Alfred, Florida, and he is currently doing great work to help producers find solutions to the devastating citrus greening disease.

He is truly one of the world's most preeminent experts in this field and I am honored to introduce him to you today.

Dr. Gmitter, thank you very much for being here.

The CHAIR. Thank you.

We will now proceed to hearing the testimony, each of our witnesses will have 5 minutes.

So that you are aware, you are going to see the numbers right there in front of you there are at 5. When 1 minute is left, the light will turn yellow, and unlike my driving, that does not mean speed up. That means that you have 1 minute left. And when it is red, that means the time is up, the 5 minutes are up.

Dr. Wolfe, will you please begin when you are ready?

STATEMENT OF DAVID W. WOLFE, PH.D., PROFESSOR OF PLANT AND SOIL ECOLOGY, HORTICULTURE SECTION, SCHOOL OF INTEGRATIVE PLANT SCIENCE, CORNELL UNIVERSITY, ITHACA, NY

Dr. WOLFE. Thank you.

Well, I would like to start by thanking Chair Stacey Plaskett, Ranking Member Neal Dunn, and Members of the Subcommittee for holding this important hearing.

I appreciate the opportunity to share with you my views on research and extension needs in this time of increasing climate variability and weather extremes.

My perspective has been shaped by more than 3 decades at Cornell University with a program focus on soil and water management and climate change adaptation and mitigation.

In addition to extension and academic research papers, I have also co-authored numerous regional and national climate assessments.

I currently am lead project director for the New York Soil Health Program, and I serve on various advisory boards relevant to today's hearing, and I teach a course on climate change and food security.

So with my few minutes I want to just highlight three major points that are gone over in more detail in my written testimony.

First, climate change impacts are turning out to be more complex, and in some cases more severe than we imagined 30 years ago.

One example of climate change surprise has been an increased risk of cold damage for woody perennials such as apples and grapes in a warming world. This can occur when warmer and more variable late winter temperatures trigger an unusually early bloom that leaves the plants vulnerable to an extended period of frost risk.

This problem has been particularly acute in my region in the Northeast, where in 2012 and again 2016, apple, grape and other fruit crop growers lost millions of dollars due to this lack of synchrony between bloom and spring frost.

Now, another area, climate models have projected for years an increase in both drought and flooding risks for many regions, but the severity of recent flooding impacts has left many areas unprepared.

As we meet here today, and as we all know, many farmers in the Midwest are suffering from a record-breaking spring flooding that has delayed planting to the point where for some the season will be a total loss. This is what concerns farmers the most, extreme weather events that are more frequent and more catastrophic than previous generations have had to face.

While not as severe, many farmers in the Northeast have also had delays in planting and flooding damage this spring and in the past 2 years, but if we go back to 2016, a record-breaking drought revealed unique vulnerabilities of this historically humid region where we lack the infrastructure to deliver water in a summer with low rainfall.

Okay. My second point is just that farmers are already responding, already adapting as they can no longer rely on historical climate norms for their region to determine what crop to plant, when to plant it, or how to grow it.

Business as usual is not a winning strategy today, and farmers are making changes accordingly. I will mention just a few here briefly. Diversification is one widely adopted and often effective approach to hedge bets in an uncertain climate. This might involve staggered planting dates, more diverse cropping mixes, or other strategies.

Improving soil health has become a popular win-win-win approach that can reduce input costs for the grower, build resilience to drought and flooding, and also sequester carbon in soils.

Farmers are more tuned in today to their integrated pest management specialists who can help them to anticipate and control a much more intense pressure from insect pests, diseases, and weeds.

And finally, one other adaptation is for some farmers an investment in larger scale farm equipment. To cover more acreage more quickly is a strategy for adapting to smaller windows of opportunity for farm operations. For example, getting in between heavy rainfall events.

Finally and most importantly perhaps, and more specific to our hearing today, for farmers to be successful they will need support from those beyond the farm. And some key areas of need that I want to mention are: first, improved delivery of regional climate data to help farmers discern between "normal bad weather" and changes in weather patterns that truly warrant adaptation investments. Also, more research is needed to improve seasonal forecasts for longer range planning beyond just the 5 day forecast into things that might cover more of the growing season.

Another one is, we need all hands on deck to develop a digital agriculture approach that will take full advantage of satellite and other data sources, new sensor network technology, and computer systems to translate massive data into usable information for field-level management. This will require new collaborations in integrating knowledge from climate science, agronomy, engineering, and computer science.

Regional centers for coordination, synergy, and accessibility of decision tools. Some land-grant universities, the regional USDA climate hubs, and others have made a start here, but a more permanent and better-funded solution is needed.

Integrating conservation policy programs with climate change adaptation and mitigation: This could warrant expansion of appropriations for soil and water conservation programs, such as those funded through the farm bill and implemented by the USDA NRCS.

Disaster assistance insurance policies, access to capital for adaptation: This is the big complex issue, but I think warranting review at this point in time to make sure our policies are relevant and adequate within the context of recurring weather-related disasters that have a link with climate change.

The possibility of a parallel track providing incentives for adaptation deserves further study.

And finally, breeding and biotechnology for climate resilient crops and livestock is important. More than just corn and beans but also specialty crops.

And finally, I see my time is up. I would like to thank the Committee again for holding this important hearing. With strategic investments in research and extension, and policies that facilitate adaptive management, there is no doubt that our farmers will be better prepared than they are today to meet the challenges and take advantage of any opportunities that a changing climate may bring.

Thank you.

[The prepared statement of Dr. Wolfe follows:]

PREPARED STATEMENT OF DAVID W. WOLFE, PH.D., PROFESSOR OF PLANT AND SOIL ECOLOGY, HORTICULTURE SECTION, SCHOOL OF INTEGRATIVE PLANT SCIENCE, CORNELL UNIVERSITY, ITHACA, NY

I would like to start by thanking Chair Stacey Plaskett, Ranking Member Neal Dunn, and Members of the Subcommittee for hosting this important hearing. I appreciate the opportunity to share with you my personal views on research and extension needs of producers in a time of increasing climate variability and more extremes in temperature and precipitation. My perspective has been shaped by more than 3 decades of experience as a faculty member at Cornell University, with a research and extension program focused on soil and water management, and climate change adaptation and mitigation strategies for the agriculture sector. I am very grateful for the grant funding I have received over the years from USDA–NIFA, USDA–SARE, and USDA-Hatch programs. I am also grateful for support from New York State for some of my regional projects, and for the collaboration with many farmers, which has been essential to creating an outreach program that addresses their needs.

In addition to peer-reviewed research and extension publications, my science communication efforts have included analyses relevant to policy-makers, such co-authoring chapters of the 2008 and 2014 National Climate Assessments, and serving as lead author of the Agriculture and Ecosystems chapters of the state-funded study, "Responding to Climate Change in New York State". Currently I am lead project director for the New York Soil Health program (*www.newyorksoilhealth.org*), am on the Advisory Boards for the New York State Water Resources Institute and the Cornell Institute for Climate Smart Solutions, and teach a course on Climate Change and Food Security.

Farmer Vulnerability to Climate Change

When I became involved in climate change research almost 30 years ago, the evidence for impacts on agriculture was subtle, and we relied heavily on climate and crop model projections to discern future impacts. But unfortunately this new challenge for agriculture has crept up on us more quickly than some expected. Farmers today are feeling the effects in real-time, and having to make difficult decisions to cope. They can no longer rely on weather patterns that for centuries have been characteristic for their region to determine what crop to plant, when to plant it, or how to grow it. In addition to an increase in drought and heat risk in many regions as one might expect with "global warming", there have also been many surprises. Below are a few examples.

Too much water

The frequency of intense rainfall events compared to historical averages has increased in the past 40 years for most regions of the U.S. (Kunkel, *et al.,* 2013). In a warmer world, more of the earth's water is in the air as water vapor, so there is more up there to come down during an upper atmosphere condensation event. Too much water can cause direct crop damage or yield losses from disease. When prolonged wet conditions in the spring or fall limit field access during planting or harvest, farmers are not able to take advantage of the climate change trend for a longer frost-free period that has been observed in most regions. Excessive rain also can lead to increased soil erosion, and runoff of sediments, fertilizers, manure, and agriculture chemicals into waterways.

As we meet here today, many farmers in the Great Plains and Midwest are suffering from a particularly severe and record-breaking spring flooding that has delayed planting to the point where, for some, the season will be a total loss (Van Dam, *et al.,* 2019). This is what concerns fa[r]mers the most: extreme weather events that are less predictable, more frequent, sometimes occur in clusters, and are more catastrophic than previous generations have had to face.

For most Americans climate change impacts on food production might mean a shortage or higher price for some of our favorite grocery items. But for the two percent of our population supplying our food, it can have devastating economic consequences. It can force farm families into increasing loan debt, taking part-time work outside the farm, or even selling part or all of the farm. These farmers may not be keeping up with the latest climate change reports or debates, but they are the ones in the trenches, dealing with the challenges on a daily basis.

Drought vulnerability in historically "humid" regions

The Northeast is typical of many humid regions, with summer rainfall usually adequate for production of field crops and hay and forage animal feedstocks. Those producing high value fruit and vegetable crops often have some capacity for supplemental irrigation for at least part of their acreage. But an increased risk of short-term summer drought has been projected for the region, reflecting an increase in crop water needs with longer, warmer summers, combined with projections of little change or a decline in summer precipitation (Wolfe, *et al.,* 2018; Hayhoe, *et al.,* 2007). The region has not invested in infrastructure to deliver water to farmlands from lakes and reservoirs as is the case in historically more arid regions. The region's vulnerability to drought was made apparent in 2016 when a severe drought reduced yields of rain-fed crops by more than half in many parts of region. Even those growing high value crops with supplemental irrigation suffered losses, either because they did not have enough equipment to keep up with demand, or because farm wells, ponds, and creeks went dry (Ossowski, *et al.,* 2017; Sweet, *et al.,* 2017).

The 2016 drought was not the end of the story for the Northeast. The following 2017 growing season was unusually wet, and many of the same farmers suffered crop (and soil) losses from heavy rains and flooding (Sweet and Wolfe 2018).

More cold damage in a warming world?

Another climate change surprise has been an apparent increased risk of cold damage for woody perennials such as apples and grapes in a warming world. This can occur when warmer and more variable late winter temperatures trigger an unusually early bloom that leaves the plant vulnerable to an extended period of frost risk. While frost damage is not a new phenomenon, a lack of synchrony between bloom and spring frost appears to be occurring more frequently in recent years, and a recent modeling study for apples suggests this trend may continue in the Northeast, at least for the next few decades (Wolfe, *et al.,* 2018). An example of the impact this can have was seen in 2012 when unusually warm temperatures in late winter led to record-breaking early flowering of many plant species (Ellwood, *et al.,* 2013). In that year apple and grape growers in the Northeast lost millions of dollars (Horton, *et al.,* 2014). Significant damage to apple buds occurred again in spring 2016 after another mild winter, followed by April frost.

More dynamic and intense pest and weed pressure

We now have overwhelming documentation that the living world is rapidly responding to climate change. Longer, warmer summers can lead to more generations of insect pests per season, and increased competition from weeds. In addition, farmers in higher latitude regions are facing new pests, weeds, and plant pathogens coming up from the south as temperatures warm and the suitable habitat for these species expands northward.

Farm-Level Adaptation Strategies

Many farmers today have seen enough evidence to be convinced that a significant change is going on with the weather patterns; one that will require a proactive, adaptive management to stabilize productivity and remain profitable. The table below provides examples of some key strategies that are being implemented in some areas as ways to build resiliency and reduce risk. (for a more thorough review, see: Walthall, *et al.,* 2012; Wolfe 2013).

- *Diversify* with more staggered planting dates, a more diverse crop variety mix, and/or diverse rotation sequences. Explore new crop and market opportunities possible with a longer growing season, and/or in relation to climate change impacts and farmer responses in other regions. This is a way to "hedge bets" in a context of uncertainty.
- *Improving soil health* is a "win-win" approach with multiple benefits, including resilience to climate variability, and capturing and storing carbon in soils (Wolfe 2019). Healthy soils have relatively high organic matter, which provides resilience to short-term droughts, flooding, and compaction. Maintaining vegetation cover as much of the year as possible with fall and winter cover crops—one of the key methods to rebuild organic matter on depleted soils—also has the benefit of reducing erosion losses during heavy rainfall events. And soil organic matter is often more than 60 percent carbon, carbon that otherwise would be in the air as the greenhouse gas, carbon dioxide.
- *Regional Integrated Pest Management* for anticipating and controlling new pests, diseases, and weeds.
- *Better water management.* This could range from building resilience through better soil management, to using new sensors and tools for optimized irrigation scheduling, to capital investment in irrigation or drainage systems.
- *Fruit crop frost protection* begins with site selection at initial planting, and methods during frost events, such as misting or air circulation fans, to reduce damage.
- *Investment in large scale farm equipment* to cover more acreage quickly is a strategy for adapting to smaller windows of opportunity (*e.g.,* between rainfall events) for farm operations such as planting or harvesting.
- *Reduce heat stress in livestock facilities* by improving design of new facilities, or improving existing facilities with better air circulation, or retrofitting with fans and sprinklers, or more sophisticated cooling systems.

Research, Extension, and Policy Needs

The adaptation strategies discussed above focus on farm-level adaptation, but for farmers to be successful they will need support from those beyond the farm. Below are several key needs where researchers, extension and other educators, government agencies, policy-makers, agriculture service providers, nonprofit organizations, and communities can play a role.

Climate change science and delivery of information to farmers

Farmers are intimately familiar with the day-to-day weather challenges on their farm, but this information is local and anecdotal. Climate scientists, through extension networks, can provide a broader view that includes data from other regions, historical analyses of trends, and climate projections. This can help farmers identify changes in weather patterns that are part of a long-term trend and warrant investment for adaptation. While some regions have reasonably effective programs for getting this information to farmers, others do not.

Seasonal climate forecasts

More research is needed to improve our ability to provide seasonal climate forecasts, for longer range planning (*e.g.,* the entire growing season). This is particularly needed in regions where the climate is not strongly influenced by ENSO cycles, for example.

Economics of climate change impacts and adaptation strategies

Impact assessments of climate change on the U.S. agriculture sector have often assumed an "autonomous" adaptation by farmers, and largely ignored the risk and costs for the agricultural sector. Also, prior analyses have often focused on the major world food crops such as corn, soybean, and wheat. More attention is needed regarding impacts and costs of adaptation of other agriculture systems, such as high-value fruit and vegetable crops, and livestock, which are major components of the agricultural economy in many regions of the U.S.

Regional centers for coordination and exchange of climate change and adaptation information

This can also increase synergy of efforts among researchers, educators, and farmers. Some land-grant universities, nonprofit organizations, and government agencies provide useful information and training for farmers and extension staff, and/or host websites with resources, climate data and decision tools for farmers (*e.g., www.climatesmartfarming.org*). But these efforts are not available in many parts of the country, and are typically under-funded and, at discontinued when short-term funding runs out. The current regional USDA climate "hubs" have provided a valuable service recently that is national in scope and been successful at coordinating regional activities, and organizing regional assessments, conferences, and webinars, despite limited funding. Establishing some version of these as a long-term and appropriately funded program of the agency would be a good alternative to what we have today.

Environmental monitoring, data analytics, and digital agriculture

The challenges imposed by climate change demand a radical transformation in information available to farmers for decision-making. The agricultural sector is not taking advantage of satellite and other data sources available, new sensor network technology, and computer systems that can translate massive data into useable information for field-level management decisions on a daily basis and for long-term land use planning. To address this will require new collaborations and integrating knowledge from meteorology, climate science, biology, ecology, engineering, and computer science. The public sector can play an important role in ensuring equity of access to all farmers.

Policy incentives and cost-sharing for climate change adaptation and conservation

Many soil and water conservation policies, such as those implemented by the USDA–NRCS [EQIP] programs, also have relevance to climate change impacts, adaptation, and mitigation. Where appropriate this could warrant an expansion of appropriations through the farm bill for some of these programs. Also, these policies should be reviewed for their impact on flexibility required for adaptation to climate change at the farm level.

Various aspects of farm policy could be reviewed in search of mechanisms to facilitate farmer adaptation to climate change without unintended or inequitable negative consequences for farmers, the environment, or markets and trade. Disaster assistance and production or income insurance policies will be an essential component of helping farmers cope with less predictable weather patterns, but the possibility of blending these with incentives for adaptation to avoid adverse impacts of climate change where appropriate deserves study.

Breeding and biotechnology for climate-resilient crop and livestock varieties

Our knowledge of plant and animal genetics, and the development of new molecular-assisted and genetic engineering techniques have increased exponentially in the past few decades. Targeting specific genes or suites of genes for environmental stress tolerance will require continued research to better understand key factors associated with climate change that determine yield. For example, evaluation of historical meteorological and yield data for Midwest grain crops has indicated that increasing minimum nighttime temperatures, as well as daytime heat stress and seasonal precipitation, are factors (Hatfield, *et al.,* 2017; Ortiz-Bobea, *et al.,* 2019). To date, most effort has been applied to major world food crops such as corn, soybean, wheat, and rice. University and other public sector emphasis should be on high value fruit and vegetable crops important to the agricultural economy of many regions of the country, but not addressed by commercial seed companies.

Concluding Remarks

Many farmers in the United States are already beginning to change practices to adapt to a less predictable climate. They will need support and access to the latest environmental monitoring technology, as well as weather and climate information, to make timely, strategic farm management decisions. With sustained major investments in research and extension, and policies that facilitate adaptive management, farmers will be better prepared to meet the challenges and take advantage of any opportunities that a changing climate may bring.

References Cited

Ellwood E.R., Templer S.A., Primack R.B., Bradley N.L., Davis C.C. (2013) *Record-breaking early flowering in the eastern United States.* PLOS-ONE 8(1): e54, 788. (*https://doi:10.1371/journal.pone.005378*).

Hatfield J.L., L. Wright-Morton, D. Hale. 2017. *Vulnerability of grain crops and croplands in the Midwest to climatic variabilities and adaptation strategies.* CLIMATIC CHANGE (*https://doi:10.1007/s/0584-017-1997-x*).

Hayhoe K., Wake C., Huntington T., Luo L., Schwartz M., Sheffield J., Wood E., Anderson B., Bradbury J., DeGaetano A., Troy T., Wolfe D.W. (2007) *Past and future changes in climate and hydrological indicators in the U.S. Northeast.* CLIMATE DYN 28: 381–407.

Horton R., Yohe G., Wolfe D.W., Easterling W., Kates R., Ruth M., Sussman E., Whelchel A. (2014) *Northeast* (Chapter 16). In: Mellilo J., Richmond T.C., Yohe G., *et al.* (eds.). THIRD NATIONAL CLIMATE ASSESSMENT. U.S. Global Change Research Program. Washington, D.C.

Kunkel K.E., Stevens L.E., Stevens S.E., Sun L., Janssen E., Wuebbles D., Rennells J., DeGaetano A., Dobson J.G. (2013) *Part 1. Climate of the Northeast U.S.* NOAA Technical Report NESDIS 142–1. NOAA, Washington D.C.

Ortiz-Bobea A., H. Wang, C.M. Carillo, T.R. Ault. 2019. *Unpacking the climatic drivers of United States agricultural yield.* ENVIRON. RES. LETT. 14(201)9064003. (*https://doi.org/10.1088/1748-9326/able75*).

Ossowski E., Mecray E., DeGaetano A., Borisoff S., Spaccio J. (2017) *Northeast drought assessments 2016–2017*. National Oceanic and Atmospheric Administration, National Integrated Drought Information System (*www.drought.gov*).

Sweet S. and D. Wolfe. March 2018. *Anatomy of a wet year: Insights from New York Farmers.* Cornell Institute for Climate Smart Solutions (CICSS) RESEARCH AND POLICY BRIEF. Issue 4. (*www.climatesmartfarming.org*)

Sweet S., Wolfe D.W., DeGaetano A.T., Benner R. (2017) *Anatomy of the 2016 drought in the Northeastern United States: Implications for agriculture and water resources in humid climates.* AGRIC. FOREST. METEOR. 247: 571–581.

Van Dam A., L. Karklis, T. Mako. June 4, 2019. *After a biblical spring, this is the week that could break the corn belt.* WASHINGTON POST. *www.washingtonpost.com.*

Walthall C.L., *et al.*, 2012. *Climate Change and Agriculture in the U.S.: Effects and Adaptation.* USDA TECH. BULL. 1935. Washington D.C. 186 pp.

Wolfe D.W., 2019. *The New York Soil Health Roadmap.* Cornell University. 39 pp. (*www.newyorksoilhealth.org*).

Wolfe D.W., A. DeGaetano, G. Peck, M. Carey, L. Ziska, J. Lea-Cox, A. Kemanian, M. Hoffmann, D. Hollinger. 2017. *Unique challenges and opportunities for Northeastern U.S. crop production in a changing climate.* CLIMATIC CHANGE 146: 231–245.

Wolfe D.W. 2013. *Climate change solutions from the agronomy perspective.* In: Hillel D. and C. Rosenzweig (eds). HANDBOOK CLIMATE CHANGE AND AGROECOSYSTEMS: GLOBAL AND REGIONAL ASPECTS AND IMPLICATIONS. Chapter 2. Imperial College Press. London.

The CHAIR. Thank you.

We will now hear from my constituent, Robert Godfrey, who is on the frontline of changing climate, assisting the farmers in the Virgin Islands through his work at the Extension Program.

Doctor?

STATEMENT OF ROBERT W. GODFREY, PH.D., DIRECTOR, AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF THE VIRGIN ISLANDS, KINGSHILL, ST. CROIX, VI

Dr. GODFREY. Good morning, Chair Plaskett, Ranking Member Dunn, Members of the Subcommittee and Chairman. Thank you for this opportunity to speak with you today.

My name is Dr. Robert Godfrey, and I am the Director of the Agricultural Experiment Station at the University of the Virgin Islands. Our faculty and staff conduct research in the disciplines of agroforestry, agronomy, animal science, aquaculture, biotechnology, and horticulture.

The cooperative extension service provides outreach to the community in agricultural and natural resources, 4–H/family and consumer sciences, and communications technology and distance learning.

Most of our research projects incorporate climate and the environment as a necessity due to our location. Currently we have research projects evaluating micro-irrigation to enhance water use efficiency for crops, mulching systems and cover crops to minimize external inputs for soil improvement, evaluating adaptive traits of local livestock breeds such as Senepol cattle and St. Croix white hair sheep, and selecting and developing field crop varieties for enhanced production in the tropics.

It is estimated that the U.S. Virgin Islands imports 90 to 95 percent of its food items, indicating that there is enormous potential market opportunity for local farmers to tap into.

Farming in the U.S. Virgin Islands is characterized by small farms averaging less than 5 acres in size. Most agricultural production inputs are imported and high shipping costs contribute significantly to the costs of production and operation.

Based upon USDA definitions, the majority of farmers in the U.S. Virgin Islands are *limited resource* and *socially disadvantaged farmers.* They face many constraints unique to small-scale tropical agriculture, such as seasonal rainfall, high incidents of pests and diseases, high organic matter turnover in the soils, high temperature and humidity, increasing frequency and intensity of extreme weather events, and limited access to financing for farm support.

In September of 2017, two Category 5 hurricanes devastated the U.S. Virgin Islands, 12 days apart, enhancing the level of destruction and hampering recovery efforts. After Hurricane Irma devastated St. Thomas and St. John, St. Croix farmers, AES, CES, the Virgin Islands Department of Agriculture, and several community groups collected and shipped relief supplies to our sister islands by commercial and private boats. Then St. Croix and Puerto Rico were hit by Hurricane Maria and suffered severe damage.

The ports of St. Croix, St. Thomas and Puerto Rico were all shut down, even just temporarily at the same time, which limited access to relief and recovery resources. Many crops were lost due to wind damage and saltwater contamination. Livestock farmers suffered damage to fences, animal pens, and loss of animals from airborne debris. As an example, the University sheep research flock lost ⅓ of its breeding ewes.

The lack of locally available resources such as irrigation supplies, seedlings, fence wire, fence posts, and animal feed made recovery efforts for all farmers difficult.

In addition to hurricanes, there have also been periods of drought in the U.S. Virgin Islands. The average annual rainfall is 51″, but in 2015 we received less than 25″ of rain. The Virgin Islands Department of Agriculture was able to offer imported feed and hay at reduced fees, but their ability to provide other services and water for farmers was very limited.

The ability for livestock farmers to sell animals was hampered by the limited capacity of the one federally inspected abattoir on St. Croix. The abattoir on St. Thomas is still not operating after suffering damage during Hurricane Irma.

The field research facilities of the Agriculture Experiment Station were severely damaged and limited our ability to conduct research for most of 2018. Our research programs are slowly coming back online but we still have a long way to go.

A proposal has been submitted by AES to the FEMA Hazard Mitigation Grant Program to develop an Agricultural Hazard Mitigation and Resiliency Plan. It will coordinate with the territory-wide Comprehensive Hazard Mitigation and Resiliency Plan managed by other units in the University.

In response to stakeholder needs after the recent storms and drought, cooperative extension service has offered training to help livestock producers rehabilitate their pastures, training for use of composting, micro-irrigation and soil conservation, workshops on restoring trees damaged by the storms and droughts using proper pruning techniques, and AES and CES staff had joined an Advisory Committee that developed a plan for recycling the large amounts of vegetative and wood debris left by the hurricanes by making that mulch available for distribution to farmers and the community.

In conclusion, I want to say that agriculture in the U.S. Virgin Islands will continue to be impacted by climate change through increased frequency and intensity of extreme weather events. These extreme events serve to highlight the importance of food security and accessibility in a remote island location such as ours.

As the University of the Virgin Islands continues to support and develop agriculture in the U.S. Virgin Islands by working with our local stakeholders and regional and Federal partners, the impact of climate change will play a significant role in the development of our resiliency, mitigation, and sustainability plans.

I thank you for this opportunity to testify before this Subcommittee and I look forward to your questions.

[The prepared statement of Dr. Godfrey follows:]

PREPARED STATEMENT OF ROBERT W. GODFREY, PH.D., DIRECTOR, AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF THE VIRGIN ISLANDS, KINGSHILL, ST. CROIX, VI

Resiliency of Agriculture in the U.S. Virgin Islands

Introduction

Good morning, Chair Plaskett, Ranking Member Dunn, and Members of the Subcommittee. Thank you for this opportunity to provide testimony for this Subcommittee.

My name is Dr. Robert Godfrey and I am the Director of the Agricultural Experiment Station (AES) at the University of the Virgin Islands. Our faculty and staff conduct research in the disciplines of Agroforestry, Agronomy, Animal Science, Aquaculture, Biotechnology and Horticulture. The Cooperative Extension Service (CES) provides outreach to the community in Agriculture & Natural Resources, 4–H/Family & Consumer Sciences and Communications, Technology & Distance Learning.

Most of our research projects incorporate climate and the environment as a necessity due to our location. Currently we have research projects evaluating micro-irrigation to enhance water use efficiency for crops, mulching systems and cover crops to minimize external inputs for soil improvement, evaluating adaptive traits of local livestock breeds such as Senepol cattle and St. Croix White Hair sheep and selecting and developing field crop varieties for enhanced production in the tropics.

Overview of Agriculture in the U.S. Virgin Islands

It is estimated that the U.S. Virgin Islands imports 90 to 95% of its food items indicating that there is an enormous potential market opportunity for local farmers to tap into. Farming in the U.S. Virgin Islands is characterized by small farms averaging less than 5 acres in size.[1] Most agricultural production inputs are imported and high shipping costs contribute significantly to the costs of operating a farm.

Based upon the USDA definitions, the majority of the farmers in the U.S. Virgin Islands are limited resource and socially disadvantaged farmers. They face many constraints that are unique to small scale tropical agriculture such as seasonal rainfall, high incidence of pests and diseases, high organic matter turnover in soils, high temperature and humidity, increasing frequency and intensity of extreme weather events, limited market, and limited access to financing for farm support.

Impact of Extreme Weather on Agriculture in the U.S. Virgin Islands

In September 2017 two category 5 hurricanes devastated the U.S. Virgin Islands only 12 days apart enhancing the level of destruction and hampering recovery efforts. After Hurricane Irma devastated St. Thomas and St. John, St. Croix farmers, AES, CES, the Virgin Islands Department of Agriculture and community groups collected and shipped relief supplies to our sister islands by commercial and private boats. St. Croix also served as a base of operations for Federal support efforts with cargo and personnel being flown back and forth between the islands' airports. Then St. Croix and Puerto Rico were hit by Hurricane Maria and suffered severe damage. The ports of St. Croix, St. Thomas and Puerto Rico were all shutdown, even just temporarily, at the same time which limited the access to relief and recovery resources.

Many crops were lost due to wind damage and saltwater contamination. Livestock farmers suffered damage to fences, animal pens and loss of animals from airborne debris. As an example, the University sheep research flock lost ⅓ of the breeding ewes in its flock. the lack of local resources available such as irrigation supplies, seedlings, fence wire, fence posts and animal feed made recovery efforts for all farmers difficult.

In addition to hurricanes, there have also been periods of drought in the U.S. Virgin Islands. The average annual rainfall is 51″[2] but in 2015 we received less than 25″ of rain. The Virgins Islands Department of Agriculture was able to offer some livestock feed and imported hay at reduced fees but their ability to provide other services and water for farmers was very limited. The ability for livestock farmers to sell animals was hampered by the limited capacity of the one federally inspected abattoir on St. Croix. The abattoir on St. Thomas is still not operating after suffering damage during Hurricane Irma.

Response to Extreme Weather Events

The field research facilities of the Agricultural Experiment Station were severely damaged and limited our ability to conduct research for most of 2018 after the Hurricane Maria. Our research programs are slowly coming back online but we still have a long way to go.

A proposal has been submitted by AES to the FEMA Hazard Mitigation Grant Program to develop an Agricultural Hazard Mitigation and Resiliency Plan. It will coordinate with the territory-wide comprehensive Hazard Mitigation and Resiliency Plan managed by other units within the University.

In response to stakeholder needs after the recent storms and drought, CES has offered training to help livestock producers rehabilitate their pastures, training on the use of composting, micro-irrigation, and soil conservation, and workshops on restoring trees damaged by storms and droughts using proper pruning techniques. AES and CES staff joined an *ad hoc* advisory committee that developed a plan for recycling the large amounts of vegetative/wood debris left by the hurricanes by making mulch that is available for distribution farmers and the community.

Conclusion

In conclusion, I want to say that agriculture in the U.S. Virgin Islands will continue to be impacted by climate change through increased frequency and intensity of extreme weather events. These types of extreme events only serve to highlight the importance of food security and accessibility in a remote island location such as ours. As the University of the Virgin Islands continues to support and develop agriculture in the U.S. Virgin Islands by working with our local stakeholders and regional and Federal partners, the impact of climate change will play a significant role in the development of our resiliency, mitigation and sustainability plans.

Thank you for the opportunity to testify before this Subcommittee. I look forward to your questions.

Supplemental Information

- St. Croix is the largest U.S. Virgin Island of approximately 84^2 miles displaying relatively flat topography. St. Thomas, 40 miles to the north, is approximately 32^2 miles and is well known for its mountainous terrain and excellent harbors. Three miles east of St. Thomas, St. John is approximately 20^2 miles, and ⅔ of this island has been designated a U.S. National Park.
- The University of the Virgin Islands was named as an 1862 land-grant institution in 1972, and is also a Historically Black College and University (HBCU).
- The U.S. Virgin Islands have been impacted by several hurricanes in the past 30 years. The most impactful storms to hit the U.S. Virgin Islands in recent history were Hurricane Hugo in 1989, Hurricane Marilyn in 1995, Hurricane Georges in 1998, Hurricane Lenny in 1999, and Hurricanes Irma and Maria in 2017.
- The most recent data for agriculture in the U.S. Virgin Islands from the 2007 Census of Agriculture[1] indicated between 2002 and 2007 the number of small farms increased, both in number (23%) and acreage occupied (15%). Farm size is small with 64% of farms in the Virgin Islands being 4 acres or less. There has been no Census of Agriculture survey conducted in the U.S. Virgin Islands since 2007 so newer data is unavailable.
- The limited availability and high cost of arable land is a major drawback to farm ownership in the U.S. Virgin Islands. Land ownership is also a concern as 41% of farms, occupying 29% of the total acreage of lands in farms, are on land rented from either the Virgin Islands Department of Agriculture or private individuals.

Figure 1. Location of farmers in the U.S. Virgin Islands [3]

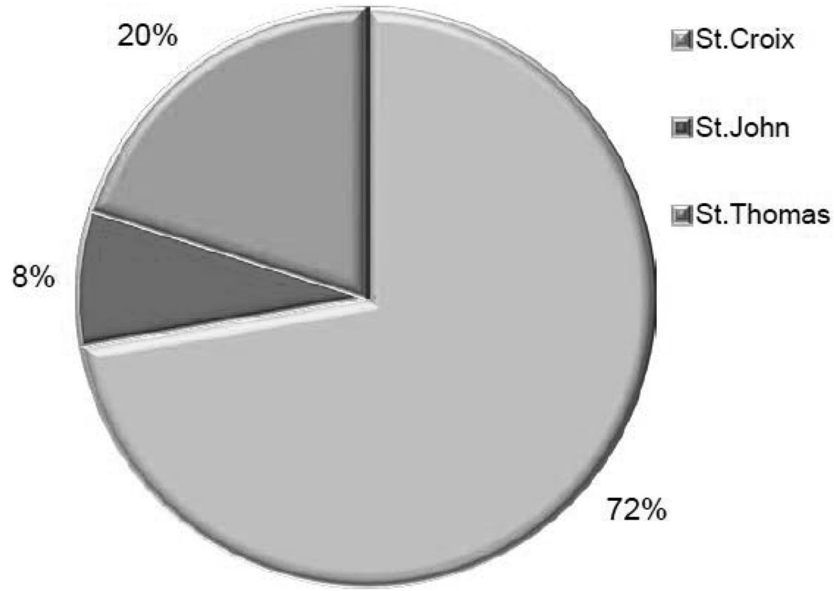


Table 1. Total acreage of farms in U.S. Virgin Islands (in percent) from survey conducted by UVI in 20183

Response Category	St. Croix	St. Thomas & St. John	Total
Number of respondents	132	49	181
Less than 2 acres	44.2	53.0	44.2
2 to 4 acres	19.9	24.5	19.9
5 to 9 acres	9.4	8.2	9.4
10 or more acres	26.5	14.3	26.5

Figure [2]. Monthly average rainfall and high and low temperatures on St. Croix (1987–2011) measured at UVI–AES Sheep Research Facility [2]

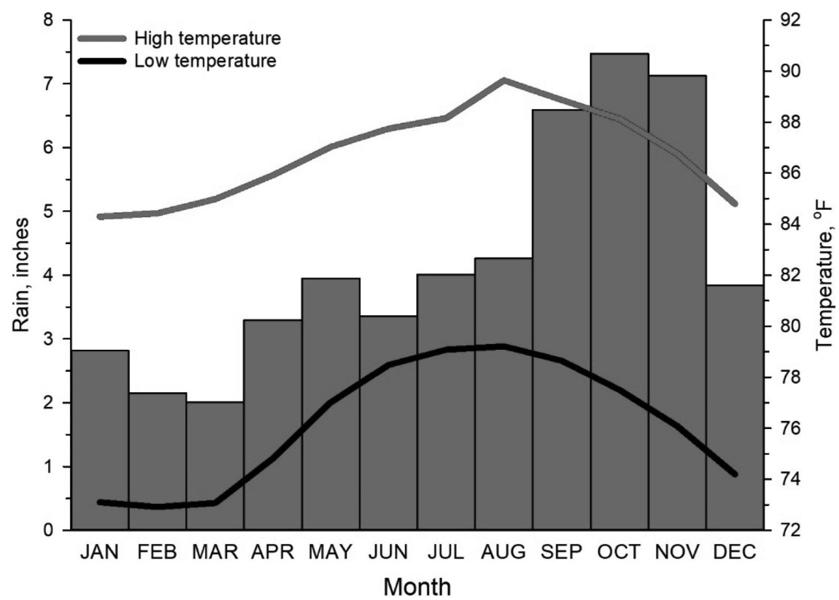


Figure [3]. Annual total rainfall on St. Croix (1987–2011) measured at UVI–AES Sheep Research Facility [2]

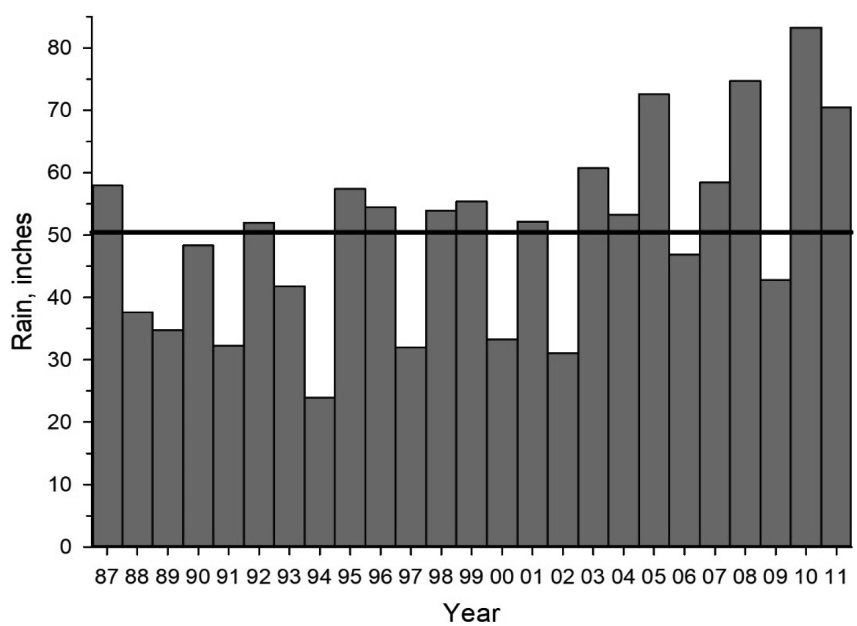
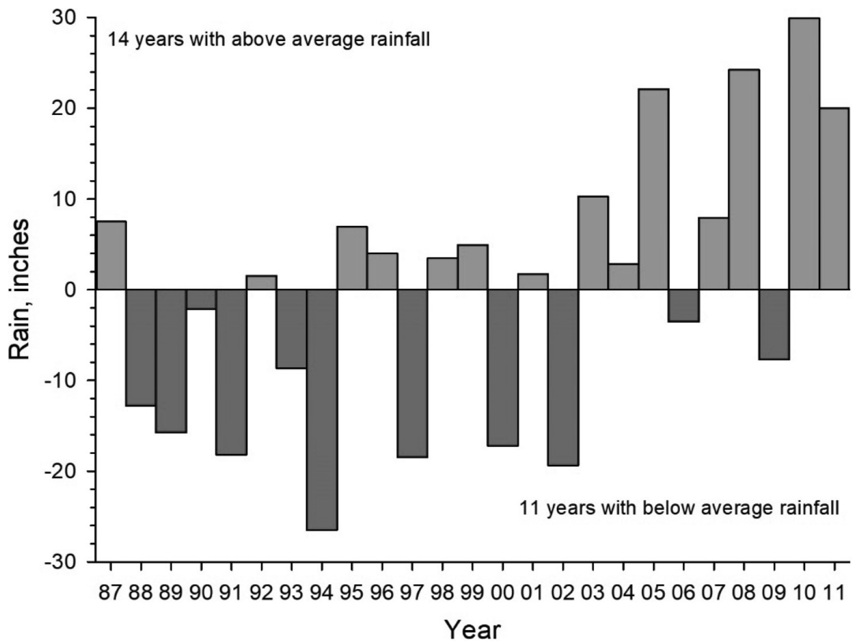


Figure [4]. Comparison of annual total rainfall to average on St Croix (1987–2011) collected at UVI–AES Sheep Research Facility [2]



[Endnotes]

[1] *2007 Census of Agriculture.* United States Department of Agriculture National Agricultural Statistics Service, Issued February 2009.

[2] Godfrey, R.W. *Impact of Drought on Livestock.* USVI Drought Monitoring Forum. August 30, 2016. Sponsored by: USDA Office of the Chief Economist, National Drought Mitigation Center, NOAA National Weather Service, USDA Farm Service Agency, USDA Natural Resources Conservation Service, UVI Cooperative Extension Service, VI Department of Agriculture, VI Climate Council.

[3] *United States Virgin Islands Agro Processing/Packaging Plant Feasibility Study.* 2018. University of the Virgin Islands, Institute for Leadership & Organizational Effectiveness.

The CHAIR. Thank you.

The next witness, if you would? Ms. Tencer?

STATEMENT OF BRISE S. TENCER, EXECUTIVE DIRECTOR, ORGANIC FARMING RESEARCH FOUNDATION, SANTA CRUZ, CA

Ms. TENCER. Thank you, Chair Plaskett, Ranking Member Dunn, and distinguished Members of the Committee. Thank you for your time and attention on this pressing issue.

Farmers have always had to manage a variety of risks, and now with climate change disruptions exacerbating these risks, with weather extremes that are modifying the lifecycle of crop pests and pathogens, delaying planting seasons, and accelerating soil degradation, farmers face new challenges that pose increased threats to both their livelihoods and their ability to produce food for a growing population.

Organic producers utilize innovative strategies that support agricultural resiliency and show exciting potential to mitigate greenhouse gas emissions.

In addition, strong market demand and high prices for certified organic farm products can help reduce economic risks for producers.

Since 1990, the Organic Farming Research Foundation has worked to foster both improvement and widespread adoption of organic farming systems across the United States. Our recent publication on risk and resiliency based significantly on USDA funded research, documents the importance of soil health, a guiding principle of organic systems, in reducing production cost and minimizing risk.

Organic systems that maintain higher soil organic matter and biological activity, improve moisture infiltration and storage, and foster efficient nutrient cycling, result in greater yield stability through weather extremes and other stresses.

Such soil-sustained crops through dry spells require less irrigation water and undergo less ponding, runoff, and erosion during heavy rains.

Organic practices such as cover cropping can enhance soil health, support management of weeds, pests, and diseases and build overall resilience to stress while sequestering carbon and mitigating greenhouse gas emissions.

The importance of crop rotation and diversification, and improving soil health, managing stresses, and reducing risk of catastrophic financial losses when one crop fails, has been well documented in both conventional and organic systems.

We believe that continued research investment is essential to realizing the full potential of organic farming strategies, and that such research can benefit all types of producers.

Our last national survey of organic farmers and ranchers across the country provided robust insight into the research needs of the organic farming community.

Based on input from nearly 2,000 certified organic operations, we can say with confidence that although research priorities vary by region, there are major commonalities in their desire for better information on soil health criteria, efficacy of amendments, weed insect disease management, and development of regionally adapted cultivars equipped to withstand region-specific climate stresses.

Our in-depth analysis of USDA organic research portfolio documents some exciting research and promising new strategies that merit further research and development into site-specific applications and practical guidelines for producers.

Several USDA studies have clearly shown that organic systems can effectively sequester soil organic carbon and reduce greenhouse gas emissions.

Further research investments can help maximize growers' ability to monitor their soil organic carbon, measure the specific impacts of their practices.

Research is also urgently needed to help all farmers reduce greenhouse gas emissions, especially nitrous oxide from fertilized or manured soils.

We greatly appreciate the USDA funding for research education and extension that is crucial to helping build resiliency and address risk.

The Sustainable Agriculture and Research and Education Program, the Organic Agriculture Research and Extension Initiative, and the Organic Transitions Program have supported hundreds of studies that help both organic and conventional farmers address the threat of climate disruption.

Thanks to these programs, farmers are using more efficient irrigation systems, adopting organic managements practices that build healthy soil, sequester carbon, and limit application of fertilizers and pesticides.

More research, education, and extension is needed to help farmers and ranchers implement the best practices for climate mitigation and adaptation for their locales and specific systems.

In addition to the organic-specific programs, we encourage other USDA research agencies, including the Agricultural Research Service and the National Institute of Food and Agriculture, to invest more in development and adoption of organic farming systems.

Extension and education is essential to delivering new skills, tools, technology into the hands of growers. As a country, I believe we are under-investing in cooperative extension programs, but organic producers are often at additional disadvantage because the organic expertise of organic extension agents varies significantly state by state.

Farmers depend on the continued capacity of NIFA and ERS to maintain expertise in a centralized location. We believe that the centralized location is essential to helping effectively share key research findings with NRCS, Risk Management Agency, and other agencies so they can also support adaptation of best practices.

These are challenging times for the people who grow our food. Thank you for your commitment and support of policies that help our nation's agricultural producers manage risk, increase resiliency, and provide food security to our population.

Thank you.

[The prepared statement of Ms. Tencer follows:]

PREPARED STATEMENT OF BRISE S. TENCER, EXECUTIVE DIRECTOR, ORGANIC FARMING RESEARCH FOUNDATION, SANTA CRUZ, CA

Chair Plaskett, Ranking Member Dunn, and distinguished Members of the Subcommittee on Biotechnology, Horticulture, and Research, thank you for your time and attention on the pressing issues of resiliency and risk in agriculture.

Since 1990, OFRF has been working to foster the continuous improvement and widespread adoption of organic farming systems. Organic producers have developed innovative strategies that support agricultural resiliency and show potential to mitigate greenhouse gas (GHG) emissions and lessen the impacts of climate change on production. In addition, strong market demand and high prices for certified organic farm products can help reduce economic risks for organic producers.

Even in the best circumstances, farmers are managing a variety of risks, including fluctuating markets, increasing production costs, and annual weather variations that may cause production challenges. Climate disruptions are increasing in intensity and frequency, which exacerbates existing risks. For instance, life cycles and geographic ranges of crop pests and pathogens are rapidly shifting, and soil health is degrading at a concerning rate (IPCC 2014, Kirschbaum, 1995; Montanarella, *et al.,* 2016). These shifts in abiotic and biotic stressors are already contributing to crop losses and threatening food security (Myers, *et al.,* 2017).

In fact, climate disruptions are having a significant impact on family farmers and ranchers around the country. In the face of global climate change, extreme weather events are becoming more common. Increasingly, farmers have to contend with severe droughts and flooding, increased heat waves, warmer winters that allow pest and disease pressures to intensify, and loss of winter chill hours that regulate bud break and fruit development in tree crops. This spring, flooding left farm fields across the Midwest under water; preliminary analysis of satellite data from the National Aeronautics and Space Administration's (NASA) Near Real-Time Global Flood mapping tool estimates 1 million acres of U.S. farmland were flooded (Huffstutter & Pamuk, 2019). Meanwhile, growers across the Southeast and the islands are continuing the hard work to recover from devastating hurricanes and tropical storms. In my home state of California, farmers and ranchers are still dealing with the aftermath of last year's record-breaking wildfires intensified by increasingly warm and dry weather. We need science-based solutions that will help farmers adapt and become more resilient to these changes.

OFRF's national survey of organic farmers and ranchers, published in the National Organic Research Agenda (NORA) report, provides an authoritative understanding of the research needs of the organic community (Jerkins & Ory, 2016). Together with Taking Stock, our analysis of USDA funded organic research, NORA informs USDA researchers, universities, agricultural extension agents, farmers, ranchers, and others to ensure research, education, and extension activities are relevant and responsive to the organic sector (Schonbeck, *et al.,* 2016).

More than 1,000 organic farmers and ranchers across the U.S. participated in OFRF's online survey. Additional input was gathered through 21 listening sessions. Based on their stated priorities, OFRF recommends intensified research funding in the areas of soil health and fertility management, weed, insect, and disease management, plant breeding to develop public cultivars better suited to organic production systems, and meeting the challenges of climate change.

Farmer-identified topics related to climate disruptions included water and soil management to cope with drought and flooding, managing new insect pest and weed species, and adapting to fluctuations in chill-time for nuts and fruit crops. One farmer put it bluntly, "*climate change is about to put me out of business. 2011 was too wet, 2012 too dry, 2013 and 2014 too wet . . . plus devastating extreme cold temps in Jan. 2014 and Feb. [2015]. How can I, as the manager deal with it?*" Another farmer lamented, "*Sadly, I think climate change is going to catch up with all of us: it is getting hard to produce crops that have been routine to me over the decades.*"

The main difference between organic and conventional approaches to these new challenges is that organic producers cannot rely on synthetic inputs. Rather, they must experiment with and tailor biological and ecological approaches to fit their unique farming practices. To be successful, organic farmers need an intimate understanding of the lifecycles and biological interactions of crops, livestock, soil life, pests, and their natural enemies, as they rely on ecological processes to address production challenges. The organic approach has potential to sequester C, mitigate GHG emissions, reduce environmental impacts related to fertilizers and pesticides, and build resiliency to changing and unpredictable weather patterns. An increased investment in research for organic systems is essential to realize this potential.

We greatly appreciate USDA's funding of research, education, and extension that is crucial to helping farmers build resiliency and address risk. The Sustainable Agriculture Research and Education (SARE) program, as well as the Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) have supported hundreds of studies that help both organic and conventional farmers around the country address the threat of climate disruption. Now, it is critical to increase our investment in research that will help farmers increase resiliency.

Building Resiliency to Climate Disruptions

Organic systems that build soil organic matter and soil health, diversify crop rotations and farm enterprises, and utilize biological and cultural approaches to nutrient, pest, weed, and disease management can make agricultural production more resilient to abiotic stresses, including those related to climate change (Blanco-Canqui and Francis, 2016; Lal, 2016). These systems are inherently knowledge-intensive and site specific, and the challenges all producers face in managing crops, livestock, soils, nutrients, and both beneficial and harmful organisms in this time of climate change are highly interconnected. Therefore, it is essential for Congress to continue supporting integrated research, education, and outreach to provide farmers with the tools, technology, and support they need to build healthy resilient farming systems that can withstand climate disruption, and to steward the land for generations to come.

Healthy Soils

As documented in our recently published Reducing Risk Through Best Soil Health Management Practices in Organic Crop Production (with funding from the USDA Risk Management Agency), soil health plays a key role in reducing production costs and risks, and will become ever more critical as climate disruption continues to unfold. The USDA Natural Resources Conservation Service (NRCS) has established four science-based principles of soil health management: keep the soil covered, maximize living roots, enhance cropping system diversity, and minimize soil disturbance. Management systems that address all of these principles build organic matter and overall soil health more effectively than adopting a single practice such as no-till or green manuring (Schonbeck, *et al.,* 2017, 2018).

Sustainable organic systems that maintain higher soil organic matter and biological activity, improve moisture infiltration and storage, and foster efficient nutrient cycling result in greater yield stability through weather extremes and other stresses. For example, while organic and conventional crop rotations in the Rodale long-term farming systems trials gave similar yields over a 35 year period, the organic systems sustained much better crop condition and 31% higher grain yield in corn during drought years (Rodale, 2011a, 2015). In another instance, regenerative range management helped a Texas ranch maintain its herd through the extreme drought of 2012 that forced other ranchers to sell livestock (Lengnick, 2016).

Healthy soils have good structure (tilth), which allows them to absorb and hold moisture, drain well, maintain adequate aeration, and foster deep, healthy crop root systems. Such soils sustain crops through dry spells, require less irrigation water, and undergo less ponding, runoff, and erosion during heavy rains (Magdoff and van Es, 2009; Moncada and Sheaffer, 2010; Rodale, 2015).

During California's recent drought, vegetable growers were faced with irrigation water use restrictions. In an OFRF-funded study conducted with Dr. Amelie Gaudin and colleagues at UC Davis, organic farmer Scott Park showed that his integrated approach to soil building, including diversified rotation, winter cover crops, minimum tillage, and applications of compost and beneficial microbes doubled his soil's moisture capacity and reduced irrigation water needs for tomato production by 6″ to 11″ per season (Gaudin, *et al.,* 2018).

Healthy, biologically active soils support plant root symbionts such as mycorrhizal fungi, and other beneficial soil microorganisms that help crops obtain nitrogen, phosphorus, and other nutrients from soil organic matter and other slow-release organic sources, thereby reducing the need for soluble nutrient applications that can threaten water quality (Kloot, 2018; Rosolem, *et al.,* 2017; Sullivan, *et al.,* 2017; Hamel, 2004; Wander, 2015b; Wander, *et al.,* 2016). In a study of 13 organic tomato fields in central California, four of the best-managed fields showed "tightly coupled nitrogen cycling" in which soil soluble nitrogen levels were low enough to protect water resources yet the crop absorbed sufficient nutrients for top yields (Bowles, *et al.,* 2015). Tight nutrient cycling not only reduces fertilizer bills and enhances crop resilience to weather extremes, but also minimizes emissions of the powerful greenhouse gas nitrous oxide from soils.

Research recommendation: Development of management strategies to promote tightly coupled nutrient cycling in other crops and regions appears quite feasible, and should be considered a top research priority for agricultural resilience to climate change.

Cover Crops

Idle, bare soil is at risk. Protracted fallow periods such as a corn-soy or vegetable rotation without winter cover crops, or the traditional wheat-fallow system for dry farming in semiarid regions can deplete soil organic matter, starve-out mycorrhizal fungi and other beneficial organisms, aggravate soil erosion and compaction, and increase fertilizer and irrigation costs (Kabir, 2018; Rillig, 2004; Rosolem, *et al.,* 2017; Six, *et al.,* 2006). Growing cover crops during the off-season can sustain soil life, conserve nutrients, sustain soil health, and increase cash crop yields.

In Mediterranean climates such as central California and the Pacific Northwest, most of the rainfall occurs in winter while intensive vegetable production takes place from spring through fall, often depending on irrigation. Currently, few of these acres are planted in winter cover crops, yet cover crops can play a vital role in water and nutrient management. During the wet winter of 2017, cover crops made the difference between prompt infiltration and prolonged ponding in fields and orchards (Kabir, 2017). In the Salinas Valley of California, an organic vegetable double crop system of spring lettuce followed by fall broccoli sustained high lettuce yields only if a winter cover crop was planted after the broccoli to recover surplus nitrogen and deliver it to the following lettuce crop; winter fallow often led to a lettuce crop failure (Brennan, *et al.,* 2017). In addition to greatly enhancing resilience, the cover crop protected water quality and reduced greenhouse gas emissions.

Organic systems studies have shown that cover crops enhance soil health, nutrient cycling and crop nutrition, crop rooting depth and moisture acquisition, and overall stress resilience in other locations, including Illinois, Minnesota, Maryland, North and South Carolina (Gruver, *et al.,* 2016; Hooks, *et al.,* 2015; Hu, *et al.,* 2015; Marshall, *et al.,* 2016; Moncada and Sheaffer, 2010; Rosolem, *et al.,* 2017). Farmers in Montana, New York, and across the U.S. are gradually increasing their use of cover crops, citing soil health, yield stability, and reduced production costs (Jones, *et al.,* 2015; Mason and Wolfe, 2018; USDA SARE, 2017).

Research recommendation: Selecting the right cover crops and management methods can be challenging, especially in low rainfall regions where cover crops can deplete soil moisture and reduce yield in the following crop (Miller, 2016). While farmers and researchers have had good results with winter pea in dryland grain rotations (Olson-Rutz, et al., ***2017), more research is urgently needed to develop a menu of best cover crop options for limited-rainfall regions throughout the western half of the U.S.***

Crop Rotation

The importance of crop rotation and diversification in improving soil health, managing weeds, pests, and diseases, and reducing risks of catastrophic financial losses when one crop fails, have been well documented in both conventional and organic systems (Mohler and Johnson, 2009; Moncada and Sheaffer, 2010; Ponisio, *et al.,* 2014). Adding a perennial grass-legume sod phase (1 to 3 years) to a rotation of annual crops can be especially effective in restoring soil health and fertility, and reducing weed populations. Crop-livestock integrated farming systems can recover much of the income foregone by rotation cropland into perennial sod through grazing and haying. Farming systems studies funded through the Organic Research and Extension Initiative and other USDA National Institute for Food and Agriculture (NIFA) programs have demonstrated the soil health and climate resilience benefits of sound crop rotations, and provided practical guidelines for designing rotations for organic systems (Cavigelli, *et al.,* 2013; Moncada and Sheaffer, 2010; Wander, *et al.,* 1994).

Management-intensive rotational grazing systems can restore grassland soil health and moisture capacity, improve forage quality, protect water resources, and greatly enhance resilience in livestock production as well as sequestering carbon in the soil. For example, North Dakota rancher Gabe Brown (2018) restored 5,000 acres of degraded crop and rangeland by applying the four NRCS principles to his crops, rotationally grazing multispecies livestock, and nearly eliminating synthetic inputs. Over a 20 year period, soil organic matter recovered from 2% to 7%, representing about 125,000 tons of carbon removed from the atmosphere; meanwhile the ranch continues to thrive economically. Other success stories with regionally-adapted rotational grazing systems abound from across the U.S. (Teague, *et al.,* 2016; The Natural Farmer, 2014–15 and 2016–17).

Research recommendation: Additional research is needed to address educational, economic, social, and logistical barriers to transitioning more of the nation's livestock production to this promising approach.

Compost and Organic Nutrient Sources

Compost, manure, and other organic sources of nutrients has long been a hallmark of organic systems, and can, when used judiciously, contribute to soil health, agricultural resilience, and mitigation of greenhouse gas emissions. In organic farming systems trials in Hawaii, Iowa, Maryland, and elsewhere, cover cropping in conjunction with compost or manure applications enhanced soil health and organic matter to a greater degree than either practice alone (Delate, *et al.,* 2015; Hooks, *et al.,* 2015). A single compost application to grazing lands in California substantially improved forage vigor and carbon sequestration (Ryals and Silver, 2013). A life cycle analysis confirmed that diverting manure from storage lagoons and yard and food wastes from landfills for composting greatly reduced net greenhouse gas impacts (DeLonge, *et al.,* 2013).

Research recommendation: Research is needed to end "organic waste" in the U.S. and ensure that municipal leaves, yard waste, food waste, and confinement manure is composted and returned to the land at rates consistent with sound nutrient management.

Crop and Livestock Breeding

Crop breeding for development of new crop varieties that perform well in soil health-enhancing organic and sustainable production systems, and that show increased resilience to drought, temperature extremes, and other weather-related stresses. In a 2015 project to identify plant breeding needs for the northeastern U.S., farmers and breeders noted, "*Cultivars are most productive under the conditions for which they were bred. Northeast growers [need] regionally-adapted varieties that were bred to thrive in the Northeast, with the climate and pests unique to our region. Furthermore, cultivars bred under conventional management—aided by synthetic fertilizer, herbicides and pesticides—will likely not be as productive under organic management.*" (Hultengren, *et al.,* 2016, page 26). Scientists have even documented a loss in the capacity of some modern crop cultivars to partner with beneficial soil microbes for nutrient uptake and disease resistance. In their work with organic producers to develop new cultivars, they have begun to restore this capacity, which can play a key role in overall agricultural resilience to climate change (Goldstein, 2015, 2016; Zubieta and Hoagland, 2016).

Over the past 15 years, several farmer-scientist participatory plant breeding teams funded through the USDA Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) have begun to address the need for new crop cultivars better suited to organic systems.

For example, the Northern Vegetable Improvement Collaborative or NOVIC (three rounds of OREI funding from 2010–2018) has released several new cultivars of tomato, sweet corn, squash, and broccoli for organic systems, with more on the way, including cucumber, cabbage, and pepper. NOVIC has produced two books to help farmers enhance organic seed systems: Organic Crop Breeding and The Organic Seed Grower.

Other OREI funded projects focus on wheat, soybean, and dry bean, including selecting improved strains of N fixing nodule bacteria (rhizobia), and development of vigorous, weed-competitive strains. One new food-grade soybean cultivar has been released (Orf, *et al.,* 2016; Place, *et al.,* 2011; Worthington, *et al.,* 2015).

Based on research confirming genetic regulation of plant root depth and extent, Kell (2011) has recommended breeding crops for larger, deeper root systems to build SOM, sequester carbon deep in the soil profile, and enhance nutrient and moisture use efficiency. Each of these plant breeding developments can contribute to soil health and risk reduction by increasing climate resilience, reducing nutrient and water input needs, and enhancing organic matter inputs to the soil.

Research recommendation: Additional long-term research investment in plant breeding for sustainable and organic systems is essential for realizing potential to enhance beneficial plant-soil-microbe interactions, nutrient use efficiency, soil carbon sequestration, and resilience to drought and other stresses. Farmers especially need regionally adapted cultivars equipped to withstand anticipated region-specific climate change stresses.

Identifying and developing livestock breeds that can tolerate weather extremes and thrive in management intensive rotational grazing systems is also a top research priority. We appreciate that, in recent years, OREI Requests for Applications include animal breeding for pasture-based organic production, and urge Congress to continue and expand funding for USDA development of public livestock breeds and crop cultivars to help all farmers and ranchers meet the climate challenge.

Conservation Agriculture and Organic

Conservation agriculture integrates crop rotations, cover crops, and organic soil amendments with no-till practices to build soil health and protect soil organic carbon from physical disturbances. However, continuous no-till production of annual crops relies on synthetic inputs for weed control and fertility. This chemical disturbance can harm soil biota and negatively impact the surrounding environment and human health. For example, normal use rates of glyphosate herbicides have been shown to inhibit mycorrhizal fungi, which play significant roles in soil carbon sequestration, nutrient cycling, and overall resilience (Druille, *et al.,* 2013; Hamel, 2004).

While organic systems require some level of physical disturbance to control weeds, they eliminate synthetic inputs and can significantly reduce tillage as well. Reduced tillage coupled with the full suite of soil health practices—crop diversification, cover cropping, organic amendments, and sound nutrient management—can enhance carbon sequestration and build climate resiliency in organic agricultural systems.

Concern has been raised that large-scale farms that adopt USDA certified organic practices through input substitution may not reduce net GHG footprints (Lorenz and Lal, 2016; McGee, 2015). What we are recommending today is research, education and extension to support a holistic approach to implementing the National Organic Standards that embraces the NRCS Soil Health Principles. One research priority is to address the socioeconomic, logistical, and policy barriers to implementation of *sustainable* organic systems that will enhance soil carbon sequestration, mitigate greenhouse gas emissions, and improve resilience on both large and smaller scale farms.

Organic Practices and Climate Mitigation

All farmers have a major stake in efforts to curb further climate change and improve the resilience of farming and ranching systems. Resilient, diversified agriculture systems, including crop-livestock integration, can help maintain and even improve economic, ecological, and social benefits for farm families in the face of dramatic exogenous changes such as climate change and price swings; and will thereby maintain and improve the nation's food security.

In addition to improving resilience to the impacts of climate changes already underway, the soil health practices outlined thus far can sequester carbon and reduce direct agricultural greenhouse gas emissions. Estimates of potential climate mitigation through widespread adoption of sustainable farming range from reducing U.S. agriculture's GHG footprint in half (Chambers, *et al.,* 2016), to making U.S. agriculture carbon negative. Organic production methods also significantly reduce greenhouse gas emissions through *decreased use of fossil fuel-based inputs.*

Several USDA supported studies have conducted in-depth comparisons of C sequestration or total net greenhouse gas footprint in organic *versus* conventional systems, which clearly show that organic systems can effectively sequester soil organic carbon and build resilience to climate disruption by implementing the NRCS principles of keeping soil covered, maintaining living roots, enhancing biodiversity, and minimizing soil disturbance. However, other greenhouse gas emissions, especially nitrous oxide from fertilized or manured soils, show more complex responses to management practices. For example, while optimal soil and nutrient management of organic production of lettuce in Colorado and tomato in California have virtually eliminated nitrous oxide losses, broccoli required so much N from organic sources to reach optimum yield that nitrous oxide emissions were estimated to negate soil carbon sequestration from best organic practices (Bowles, *et al.,* 2015; Li and Muramoto, 2009; Toonsiri, *et al.,* 2016).

Research recommendation: More research, education, and extension is needed to help farmers and ranchers implement the best practices for climate mitigation and adaptation for their locales, climates, soils, crop mixes, and production systems. Research is critical to developing effective tools for organic farmers and ranchers, but we need to ensure this information is verified, delivered, demonstrated, and adopted by the agricultural community. The funding and support of the University Extension system is critical to completing this cycle and ensuring that Federal research funding produces farming strategies that are widely adopted. We need trained Extension personnel to do this work. Farmers obtain their information from many sources, but they need trusted scientific resources to be successful.

Conclusion

We greatly appreciate the support Congress has provided for key USDA programs that address research, education, and extension for organic and sustainable agriculture. These programs have been on the cutting edge of addressing climate change and helping farmers build resiliency and manage risk. The Sustainable Agriculture Research and Education (SARE) program, as well as the Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) have supported hundreds of studies that help both organic and conventional farmers build soil health, reduce greenhouse gas emissions, sequester carbon, and address the threat of climate disruption. Thanks to these programs, farmers are using more efficient irrigation systems and adopting organic management practices to limit the application of fertilizers and pesticides as well as build the health and resiliency of their soil.

SARE, ORG, and OREI programs invest in innovative research that helps farmers be more resilient and adaptable to climate disruptions. The SARE program has made huge contributions in many areas, especially cover cropping, rotational grazing, local and regional food systems, and agroecology systems research. In general, SARE has a strong focus on delivery of information to the farming community. ORG has prioritized research related to the impacts of crop rotation, livestock-crop system integration, tillage, cover crop, and fertility inputs on greenhouse gas mitigation and other ecosystem services. ORG has also helped address barriers to successful transition to organic practices. OREI has greatly advanced our understanding of best soil, nutrient, crop, weed, pest, and disease management for organic systems, and has provided vital support for development of crop cultivars and, more recently, livestock breeds suited to organic production. OFRF thanks Congress for investing in these crucial programs.

However, adaptation strategies will require both short- and long-term changes, including cost-effective investments in new technologies, water infrastructure, emergency preparation for response to extreme weather events, development of resilient crop varieties that tolerate temperature and precipitation stresses, building soil health, and adopting new or improved land use and management practices. More research is necessary to understand the challenges, and to create solutions.

Researchers have identified some promising new strategies that merit further research and development into practical guidelines for producers. Additional research is needed to bridge the remaining gaps between findings to date and practical application in the context of a particular farm, soil type, climate, crop mix, and production system. Producers need guidance on context-specific management practices, including a menu of options that they can apply to their specific agricultural systems. Farmers also need practical, reliable tools to monitor soil organic carbon (SOC) and measure the impact of their practices on greenhouse gas (GHG) emissions.

Research is only the first step. Farmers will require continued and enhanced support to take the results of the research and integrate relevant components into their farming operations. It is critical to our success that farmers are provided adequate education, training, and technical assistance. Building and expanding our current Extension programs to support farmers during these difficult transitions is essential for farmers to acquire new skills, tools, and technology necessary to adapt to climate change. Programs that support the delivery and dissemination of information into the hands of America's farmers and ranchers are more important than ever. Extension and education for farmers is key, yet organic expertise of Extension agents varies significantly state by state. Organic producers in all parts of the country need to be served effectively by Extension. Congress has worked hard to increase the funding for important research programs at USDA; much more support is needed to ensure that both basic and applied research is available and more easily adopted by the farmers and ranchers around the country that are on the front lines of climate change.

We urge Federal policy-makers to prioritize support and oversight of Federal farm bill policies and programs that enable farmers and ranchers to adopt sustainable and organic agricultural production systems to address the challenges posed by a rapidly changing climate. We encourage USDA research, education, and economic divisions such as the Agriculture Research Service (ARS) and National Institute of Food and Agriculture (NIFA) to invest more in the improvement and adoption of organic farming systems, and to prioritize addressing solutions that help farmers be more sustainable and successful in the face of changing agricultural conditions. The capacity of NIFA to support outstanding research, and the Economic Research Service to provide unbiased analysis of agricultural economics, helps support farmers and strengthen our agricultural system. Maintaining this capacity and expertise in a centralized location will help ensure these agencies continue to serve the agriculture community in a coordinated and efficient manner.

Coordination and sharing of key research findings with agencies such as the National Resources Conservation Service (NRCS) and Risk Management Agency (RMA) is critical to ensuring farmers can implement these best practices. Both NRCS and RMA programs provide support for farmers managing and addressing risk. In the past, NRCS has struggled to support organic producers in simultaneously planning, implementing, and complying with conservation and organic standards. Although NRCS has expanded and significantly improved their outreach and services to organic producers across the country, several conservation measures that help farmers build resilience are sometimes penalized in crop insurance programs. The farm bill did make it easier for farmers to integrate cover cropping practices on their farms. Thanks to new language in the farm bill, it will be easier for RMA to include cover cropping in their list of Good Farming Practices. We believe the time is now for RMA to amend Good Farming Practices and conservation practice guidance to provide that all NRCS conservation practices and enhancements are automatically recognized as Good Farming Practices by RMA, without any caveats or qualifications. In our view, no farmer should be penalized or lose coverage under any crop insurance policy for using conservation practices and enhancements that are approved by NRCS.

These are challenging times for the people who grow our food, and we urge Congress and USDA to ensure Federal programs that include research, education, extension, and program implementation support organic producers and other farmers and ranchers that seek to integrate organic practices into their operations. Thank you for your commitment and support of policies that will help our country's agricultural producers manage risk, increase resiliency, and provide food security for our population.

References

Blanco-Canqui, H., and C.A. Francis. 2016. *Building resilient soils through agroecosystem redesign under fluctuating climatic regimes.* J. SOIL & WATER CONSERV. 71(6): 127A–133A.

Bowles, T.M., A.D. Hollander, K. Steenwerth, and L.E. Jackson. 2015. *Tightly-Coupled Plant-Soil Nitrogen Cycling: Comparison of Organic Farms across an Agricultural Landscape.* PLOS ONE. *http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0131888*.

Brown, G. 2018. *Dirt to Soil: One Family's Journey into Regenerative Agriculture.* Chelsea Green Publishing, White River Junction, VT. 223 pp.

Cavigelli, M.A., Teasdale, J.R., and J.T. Spargo. 2013. *Increasing Crop Rotation Diversity Improves Agronomic, Economic, and Environmental Performance of Organic Grain Cropping Systems at the USDA–ARS Beltsville Farming Systems Project.* CROP MANAGEMENT 12(1) Symposium Proceedings: USDA Organic Farming Systems Research Conference. *https://dl.sciencesocieties.org/publications/cm/tocs/12/1*.

Chambers, A., R. Lal, and K. Paustian. 2016. *Soil carbon sequestration potential of U.S. croplands and grasslands: implementing the 4 per Thousand Initiative.* J. SOIL & WATER CONSERV. 71(3): 68A–74A.

Delate, K., C. Cambardella, and C. Chase. 2015. *Effects of cover crops, soil amendments, and reduced tillage on carbon sequestration and soil health in a long-term vegetable system.* Final report for ORG project 2010–03956.

DeLonge, M.S., R. Ryals, and W.L. Silver. 2013. *A lifecycle model to evaluate carbon sequestration potential and greenhouse gas dynamics of managed grasslands.* ECOSYSTEMS 16: 962–979.

Druille, M., Cabello, M.N., Omacini, M., and Golluscio, R.A. 2013. *Glyphosate reduces spore viability and root colonization of arbuscular mycorrhizal fungi.* APPLIED SOIL ECOLOGY 64: 99–103; doi: *https://doi.org/10.1016/j.apsoil.2012.10.007*.

Gaudin A., Park S., Lloyd M., Azimi A., Velasco R., and Renwick, L. 2018. *Developing integrated irrigation management strategies to improve water and nutrient use efficiency of organic processing tomato in California.* Final report to Organic Farming Research Foundation.

Goldstein, W. 2015. *Breeding corn for organic farmers with improved N efficiency/N fixation, and protein quality.* PROCEEDINGS OF THE ORGANIC AGRICULTURE RESEARCH SYMPOSIUM, LaCrosse, WI February 25–26, 2015. *http://eorganic.info/node/12972*.

Gruver, J., R.R. Weil, C. White, and Y. Lawley. 2016. *Radishes A New Cover Crop for Organic Farming Systems. http://articles.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farming-systems*.

Hamel, C. 2004. *Impact of arbuscular mycorrhizal fungi on N and P cycling in the root zone.* CAN. J. SOIL SCI. 84(4): 383–395.

Hooks, C.R., K.H. Wang, G. Brust, and S. Mathew. 2015. *Using Winter Cover Crops to Enhance the Organic Vegetable Industry in the Mid-Atlantic Region.* Final report for OREI project 2010–01954. CRIS Abstracts.*

Hu, S., S. Hu, W. Shi, A. Meijer, and G. Reddy. 2015. *Evaluating the Potential of Winter Cover Crops for Carbon Sequestration in Degraded Soils Transitioning to Organic Production.* Project proposal and final report for ORG project 2010–04008.

Huffstutter, P.J., and Pamuk, H. 2019. "1 Million Acres of Midwest Farmlands Flooded as Corn Planting Deadlines Approach." *Insurance Journal. https://www.insurancejournal.com/news/midwest/2019/04/01/522389.htm*.

Hultengren, R., M. Glos, and M. Mazourek. 2016. *Breeding Research and Education Needs Assessment for Organic Vegetable Growers in the Northeast.* (Dataset). eCommons Digital Repository at Cornell University, 35 pp.

Intergovernmental Panel on Climate Change (IPCC). 2014. CLIMATE CHANGE 2014: MITIGATION OF CLIMATE CHANGE, WORKING GROUP III CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. *https://www.ipcc.ch/report/ar5/wg3/. Chapter 11 Agriculture, Forestry, and Other Land Use (AFOLU),* and *Annex II Metrics and Methodology.*

Jerkins, D. and J. Ory. 2016. *2016 National Organic Research Agenda: Outcomes and Recommendations from the 2015 National Organic Farmer Survey and Listening Sessions.* Organic Farming Research Foundation (*www.ofrf.org*).

Jones, C., R. Kurnick, P. Miller, K. Olson-Rutz, and C. Zabinski. *2015 Montana Cover Crop Survey Results.* Dept. of Land Resources and Environmental Sciences, Montana State University. 15 pp.

Kabir, Z. 2018. *Rethinking the nutrient management paradigm for soil health.* NRCS webinar, August 14, 2018. Science and Technology Training Library. *http://www.conservationwebinars.net/listArchivedWebinars*.

Kell, D.B. 2011. *Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration.* ANN. BOT. 108(3): 407–418.

Kirschbaum, M.U.F. 1995. *The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage.* SOIL BIOLOGY AND BIOCHEMISTRY. 27(6): 753–760.

Kloot, Robin. 2018. *Using adaptive nutrient management to answer "how much fertilizer do you actually need?"* NRCS webinar May 8, 2018. Science and Technology Training Library. *http://www.conservationwebinars.net/listArchivedWebinars*.

Lal, R. 2016. *Beyond COP21: Potential challenges of the "4 per thousand" initiative.* J. SOIL & WATER CONSERV. 71(1): 20A–25A.

Lengnick, L. 2016. *New Times, New Tools: Cultivating Climate Resilience on Your Organic Farm. http://articles.extension.org/pages/73466/new-times-new-tools:-cultivating-climate-resilience-on-your-organic-farm*.

Li, C., Salas, W. and Muramoto, J. 2009. *Process Based Models for Optimizing N Management in California Cropping Systems: Application of DNDC Model for nutrient management for organic broccoli production.* Conference proceedings 2009 California Soil and Plant Conference, 92–98. Feb. 2009. *http://ucanr.edu/sites/calasa/files/319.pdf*.

Lorenz, K., and R. Lal. 2016. *Environmental Impact of Organic Agriculture.* ADVANCES IN AGRONOMY. 139: 99–152.

Magdoff, F. and van Es, H. 2009. *Building Soils for Better crops,* 3rd ed. Sustainable Agriculture research and Education (SARE). *http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*.

Marshall, M.W., P. Williams, A. Mirzakhani Nafchi, J.M. Maja, J. Payero, J. Mueller, and A. Khalilian. 2016. *Influence of Tillage and Deep Rooted Cool Season Cover Crops on Soil Properties, Pests, and Yield Responses in Cotton.* OPEN JOURNAL OF SOIL SCIENCE, 6, 149–158. *http://dx.doi.org/10.4236/ojss.2016.610015*.

Mason, C.W., and D.W. Wolfe. 2018. *Survey of Costs, Constraints, and Benefits of Soil Health in New York: Initial Report and Summary.* REDUCED TILLAGE IN ORGANIC SYSTEMS FIELD DAY PROGRAM HANDBOOK, July 31, 2018, Cornell University Willsboro Research Farm, Willsboro NY, pp 8–9. *https://rvpadmin.cce.cornell.edu/uploads/doc_699.pdf*.

McGee, J.A., 2015. *Does certified organic farming reduce greenhouse gas emissions from agricultural production?* AGRIC. HUM. VALUES 32, 255–263.

Miller, P., 2016. *Using cover crop mixtures to improve soil health in low rainfall areas of the northern plains.* Final report for Western SARE project SW11–099, 40 pp. *http://landresources.montana.edu/soilfertility/documents/PDF/reports/CCMFinalRptSW11-099Apr2016.pdf*.

Mohler, C.A. and S.E. Johnson. 2009. *Crop Rotations on Organic Farms.* Sustainable Agriculture research and Education (SARE) and Natural Resource, Agriculture and Engineering Service (NRAES). 156 pp. *http://www.sare.org/Learning-Center/Books*.

Moncada, K., and Sheaffer, C., 2010. RISK MANAGEMENT GUIDE FOR ORGANIC PRODUCERS. U. Minnesota. 300 pp. Chapter 13, *Winter Cover Crops. http://organicriskmanagement.umn.edu/*.

Myers, S.S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., Dangour, A. D., Huybers, P. 2017. *Climate change and global food systems: Potential impacts on food security and undernutrition.* ANNUAL REVIEW OF PUBLIC HEALTH. 38. 259–277.

Olson-Rutz, K., C. Jones, and P. Miller. 2010. *Soil nutrient management on organic grain farms in Montana.* Montana State University Extension bulleting EB0200, 16 pp. *http://msuextension.org/publications/AgandNaturalResources/EB0200.pdf*.

Orf, J.H., T.E. Michaels, M.J. Sadowsky, and C.C. Sheaffer. 2016. *Improving soybean and dry bean varieties and Rhizobium strains for organic systems.* Final report on OREI project 2011–01942.

Place, G.T., S.C. Reberg-Horton, D.A. Dickey and T.E. Carter. 2011. *Identifying soybean traits of interest for weed competition.* CROP SCIENCE 51: 2642–2654.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2014. *Diversification practices reduce organic to conventional yield gap.* PROC. R. SOC. B 282, 2014 1396.

Rillig, M.C. 2004. *Arbuscular mycorrhizae, glomalin, and soil aggregation.* CAN. J. SOIL SCI. 84(4): 355–363.

Rodale Institute. 2014. *Regenerative organic agriculture and climate change: a down-to-earth solution to global warming.* 16 pp. *https://rodaleinstitute.org/assets/RegenOrgAgricultureAndClimateChange_20140418.pdf*.

Rosolem, C.A., K. Ritz, H. Cantarella, M.V. Galdos, M.J. Hawkesford, W.R. Whalley, and S.J. Mooney. 2017. *Enhanced plant rooting and crop system management for improved N use efficiency.* ADVANCES IN AGRONOMY 146: 205–239.

Ryals, R., and W.L. Silver. 2013. *Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands.* ECOL. APPL. 23(1): 46–59.

Schonbeck, M., Jerkins, D., and J. Ory. 2016. *Taking Stock: Analyzing and Reporting Organic Research Investments, 2002–2014.* Organic Farming Research Foundation (*www.ofrf.org*).

Schonbeck, M., Jerkins, D., and J. Ory. 2017. *Soil Health and Organic Farming: Building Organic Matter for Healthy Soils: An Overview.* Organic Farming Research Foundation (*www.ofrf.org*), 39 pp.

Schonbeck, M., Jerkins, D., and Snyder, L.D. 2018. *Soil Health and Organic Farming: Organic Practices for Climate Mitigation, Adaptation, and Carbon Sequestration.* Organic Farming Research Foundation (*www.ofrf.org*), 79 pp.

Six, J., S.D. Frey, R.K. Thiet, and K.M. Batten. 2006. *Bacterial and Fungal Contributions to Carbon Sequestration in Agroecosystems.* SOIL SCI. SOC. AM. J. 70(2): 555–569.

Sullivan, D. M., E. Peachey, A.L. Heinrich, and L.J. Brewer. 2017. *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon.* Oregon State Extension Bulletin EM 9165.

Teague, R. 2016–17. *Regeneration of soil by multi-paddock grazing.* Transcript of Sept. 7, 2016 presentation at Harvard by Jack Kittredge. *The Natural Farmer,* winter 2016–17: B26–B30.

The Natural Farmer 2014–15 Grazing and *2016–2017 Carbon Farming.*

Toonsiri, P., S.J. Del Grosso, A. Sukor, and J.G. Davis. 2016. *Greenhouse Gas Emissions from Solid and Liquid Organic Fertilizers Applied to Lettuce.* J. ENVIRONMENTAL QUALITY Vol. 45 No. 6, p. 1812–1821.

USDA Sustainable Agriculture Research and Education (SARE) 2017. *Annual cover crop survey reports. http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/Cover-Crop-Surveys*.

Wander, M. M., 2015b. *Soil Fertility in Organic Farming Systems: Much More than Plant Nutrition. http://articles.extension.org/pages/18636/soil-fertility-in-organic-farming-systems:-much-more-than-plant-nutrition*.

Wander, M., N. Andrews, and J. McQueen. 2016. *Organic Soil Fertility. http://articles.extension.org/pages/18565/organic-soil-fertility*.

Worthington, M., S.C. Reberg-Horton, G. Brown-Guedira, D. Jordan, R. Weisz, and J.P. Murphy. 2015. *Morphological Traits Associated with Superior Weed Suppressive Ability of Winter Wheat against Italian Ryegrass.* CROP SCIENCE 55: 50–56.

Zubieta, L. and L.A. Hoagland. 2017. *Effect of Domestication on Plant Biomass and Induced Systemic Resistance in Tomato (**Solanum lycopersicum L.**).* Poster Number 1209, Tri-Societies Meetings, Tampa, FL, Oct. 24, 2017.

Mr. COX [presiding.] Thank you. And Mr. Godwin, please begin when you are ready.

STATEMENT OF SAM GODWIN, APPLE, PEAR, AND CHERRY GROWER, GODWIN FAMILY ORCHARD, TONASKET, WA

Mr. GODWIN. Thank you, Chair Plaskett and Ranking Member Dunn for the opportunity to testify before the Subcommittee today.

I am Sam Godwin. I operate a family organic farm of 300 acres with my wife and daughter. I also partner with my brother to run another 85 acre orchard that was our father's farm.

Growing up in the center of an orchard has many rewards, but the business-related issues that our industry is facing can be overwhelming at times. I am here today to share some of my experiences from the farm to underscore the importance of research and extension for our future.

Emerging or evolving threats come in many forms. For example, pests like brown marmorated stink bug and spotted wing drosophila that were previously not present in our region now have become established in some areas because of changing weather patterns that prevent the larva from being killed by sustained cold temperatures over the winter.

Fire blight, which is a debilitating bacterium that infects pears and apple trees when spring weather is warmer or wetter than normal, has become an increasing challenging condition and an economic reality for growers.

In 2018 alone, a sobering 88 percent of pear, 17 percent of apple acreage was impacted by fire blight in Washington State, resulting in an estimated $37 million loss.

Changes in seasonal weather patterns are also forcing growers to pursue more tools to prevent sunburn in the orchards and needs to come up with an inventive solution to prevent heat-related storage disorders, post-harvest.

Our growers have long recognized the need to invest in pursuing solutions to these challenges that have assessed themselves on every box of tree fruit commercially sold since 1969 through the creation of the Washington Tree Fruit Research Commission.

Since 2013, growers have also funded an additional $32 million tree fruit endowment at Washington State University. However, these investments by industry only take us so far. Federal research programs like ARS and SCRI are critical to leveraging grower resources to address the multitude of challenges that our growers and packers are facing on a daily basis.

We appreciate the funding increase Congress has provided recently. We are especially pleased to see funding provided to create a new scientist position focusing on pear genetics and genomics which will be housed down the road from my orchard in the Wenatchee ARS facility. Unfortunately, in spite of these funds being provided more than a year ago, due to the glacial pace of ARS hiring process, this position has yet to even be advertised.

This is part of a much larger problem, as hundreds of vacant scientist and support positions, many due to retirements, are remaining open at ARS for years. These positions have been funded by Congress. We would appreciate any help that Members of this Subcommittee can make to encourage ARS to eliminate this HR bottleneck and fill these much-needed positions.

The SCRI has also provided great benefits to the specialty crop industry. A primary example is the RosBREED Program, which delivered breeding tools to accelerate the commercialization of tree fruit varieties and enhanced disease-resistant and superior consumer attributes in enhancing the resiliency for growers' operations by reducing production costs and increasing returns.

Unfortunately, a drafting error in last year's farm bill removed the Secretary of Agriculture's authority to waive the hundred percent matching requirement for the SCRI. Because of the change in rules halfway through the budget cycle, scientists have had to withdraw several valuable projects from consideration. I request that you work with your Senate counterparts to fix this drafting error without delay so that these, as well as future valuable, projects are not lost.

Research means nothing without a focused effort to get the information discovered into the hands of the growers. We encourage you to reintegrate Federal investment into extension activities through the Hatch Act and the Smith-Lever Act.

Agriculture research is most successful with the investment and support of industry, Federal Government, and university extension systems. This success is modeled in Washington State, where ARS scientists work across the parking lot from the WSU scientists who both utilize the Tree Fruit Research Commission and other commodity organizations for funding.

Today tree fruit growers find themselves caught in a business that requires significant investment and long cycle improvements with customers and consumers who want short-term benefits. When you add on the additional risk created by new unknown cultivar, changing weather patterns, and new pests, we end up in a very high-stakes game that can drain your working capital in a single season.

Federal investment and research is key to ensuring that we can continue to provide top-quality American-grown apples, pears, and cherries to consumers.

Once again, I would like to thank the Subcommittee for giving me the opportunity to testify before you today. I am happy to answer any questions that you may have.

[The prepared statement of Mr. Godwin follows:]

PREPARED STATEMENT OF SAM GODWIN, APPLE, PEAR, AND CHERRY GROWER, GODWIN FAMILY ORCHARD, TONASKET, WA

Thank you, Chair Plaskett and Ranking Member Dunn, for the opportunity to testify before the Subcommittee today on the research and extension needs of tree fruit producers when it comes to increasing resiliency and mitigating risk.

I am Sam Godwin. I operate a family organic farm of 300 acres with my wife and oldest daughter. I also partner with my brother on another 85 acre orchard that was our father's farm. I have been tied to the industry for as long as I can remember. Growing up in the center of an orchard has many rewards but the business-related issues that our industry is facing can be overwhelming at times. I am here today to share some of my experiences from the farm to underscore the importance of research and extension for our future. I spend much of my time working with others from within our industry to help ensure that our children experience the same opportunities in the future as farmers that we did.

As a farmer, you learn that there are many things that are outside of your control. You learn to trust the process and have faith in your plans or actions. The problem we face is straightforward—we grow products that are not increasing in value at the same rate as input costs.

As a labor-intensive specialty crop industry, we rely on improved technological breakthroughs to drive future competitive advantages with our commodities. Today we find ourselves caught in a business that requires significant investments in long-cycle improvements, with customers and consumers who want short-term benefits. When you add on the additional risk created by new unknown cultivars, changing weather patterns, and new pests, we end up in a very high stakes game that could drain your working capital in a single season.

The Pacific Northwest is home to family-owned orchards like mine that provide approximately 67 percent of the apples, 74 percent of the pears, and 73 percent of the sweet cherries grown in the United States. Roughly 30 percent of each commodity is exported each season. Together, these crops are valued at an average of $3 billion annually, and create tens of thousands of jobs in rural communities throughout our region.

There are a number of reasons why our growers are so successful in what they do. One is our arid climate, consisting of cool nights and hot days during the growing season. A second is the innovative and collaborative nature of our industry, and our recognition that investments in new ideas are essential to staying ahead of the constantly-evolving threats to our continued success.

Emerging or evolving threats come in many forms. For example, pests like the Brown Marmorated Stink Bug and the Spotted Wing Drosophila (SWD) that were previously not present in our region have now become established in some areas because changing weather patterns have prevented larvae from being killed by sustained cold temperatures over the winter. Changing weather patterns have also contributed to our growers now needing to fight three or four generations of codling moth per season, instead of the two generations they faced twenty years ago.

It should be noted that SWD is considered a quarantine pest for cherries, and codling moth for apples, in some key export markets for these fruits—meaning that a finding of these pests in a shipment of fruit can jeopardize future access to these important markets.

Fire blight, which is a debilitating bacterium that infects pear and apple trees in years when the spring weather is warmer and wetter than normal, has become an increasingly challenging condition and economic vulnerability for growers. In 2018 alone, a sobering 88 percent of pear and 17 percent of apple acreage was impacted by fire blight to some degree, resulting in losses of an estimated $37 million.

Changes in seasonal weather patterns are also forcing growers to pursue more tools to prevent sunburn in the orchard, and the need to come up with inventive solutions to prevent heat-related storage disorders post-harvest. In drought years, growers in some irrigation districts are facing water shortages just at the time that they need more water to protect the fruit from burning during the heat of summer.

Our growers have long recognized the need to invest in pursuing solutions to these ever-evolving challenges. In 1969, Washington State tree fruit growers voted to assess themselves on every box of apples, pears, and cherries commercially sold to establish and maintain the Washington Tree Fruit Research Commission (WTFRC). Last year alone, the WTFRC funded more than $4.5 million in research projects to address priorities of our growers. In 2013, we voted to impose an additional assessment on ourselves to fund a $32 million Tree Fruit Endowment at Washington State University (WSU). This endowment supports up to ten new research and extension positions, focusing on enhancing orchard and post-harvest operations. This is the largest contribution to WSU in the university's history.

Ongoing projects funded by the WTFRC that deal with resiliency and mitigating risk include: maximizing the use of limited irrigation water to reduce stress on pear trees; modeling the effect of changing weather patterns on pests of concern; and improving soil health by looking at the effect of woodchip mulch, mowing, and cut grass that is blown into the tree strips. Dr. Whiting of WSU is also looking at the use of nanocrystals to reduce cold damage in apples and cherries. This is only a glimpse of the work tree fruit growers are supporting through the WTFRC.

However, these investments by industry only take us so far. Federal research programs like the Agricultural Research Service (ARS) and the Specialty Crop Research Initiative (SCRI) are critical to leveraging grower resources to address the multitude of challenges that our growers and packers are facing on a daily basis.

There are two ARS facilities in Washington State that conduct research on issues that are important to our growers: the Temperate Tree Fruit and Vegetable Research laboratory in Wapato, and the Physiology and Pathology of Tree Fruits Research laboratory in Wenatchee. Research conducted at these two laboratories have yielded many benefits for growers through the years, ranging from innovative methods for pest control to game changers in improving the post-harvest storage of apples.

For years, ARS has been level funded while costs have increased, leaving research stations struggling to meet staff and infrastructure needs. We appreciate the increase that Congress provided to ARS salaries and expenses, as well as buildings and facilities, in Fiscal Year[s] 2018 and 2019. We were especially pleased to see funding provided to create a new scientist position focusing on pear genetics and genomics, which will be housed in the ARS facility in Wenatchee.

This has been a high priority of the pear industry for more than a decade. While there are countless ways a scientist with these qualifications can provide benefits to the industry, the development of a dwarfing rootstock for pears is something growers have long sought. By making trees shorter, it reduces the need for workers to use ladders in the orchard—enhancing safety and reducing labor needs at a time when finding an adequate number of workers for activities ranging from pruning to picking is becoming increasingly difficult. Growers have invested substantial resources in pursuing this goal, and this scientist will play a key role in achieving this objective.

Unfortunately, in spite of these funds being provided more than a year ago, due to the glacial pace of ARS's hiring process, this position has yet to even be advertised. This is part of a much larger problem, as hundreds of vacant scientist and support positions—many due to retirements—are remaining open at ARS for years. These positions have been fully funded by Congress, and we would appreciate any effort the Members of this Subcommittee can make to encourage ARS to eliminate this HR bottleneck and fill these much-needed positions.

In addition to the Federal resources dedicated to agricultural research through ARS, the SCRI has also provided great benefits to the specialty crop industry since day one. During the first year of the SCRI program, a grant provided to a group led by Carnegie-Mellon was used to develop a machine vision system. That system is now a critical component of an automated robotic harvester that has been developed by a California company with support from the WTFRC, providing a new tool to help growers adapt to an increasingly scarce labor supply. This next season will be the first in which it will be in, albeit limited, commercial operation.

Another example of an SCRI success is the RosBREED program, which is delivering breeding tools to accelerate the commercialization of tree fruit varieties with enhanced disease resistance and superior consumer attributes—enhancing the resiliency of growers' operations by reducing production costs and increasing returns.

We would like to thank Congress, and in particular the House and Senate Agriculture Committees, for fully funding the SCRI in last year's farm bill. While we certainly recognize the challenges that citrus growers are facing with citrus greening, the decision to fund efforts to combat that devastating condition separate from the overall SCRI program frees up much sought-after resources in this over-subscribed program for other important priorities.

Unfortunately, it was discovered several months ago that a drafting error in the farm bill removed the U.S. Secretary of Agriculture's authority to waive the 100 percent matching requirement for the SCRI. This made SCRI unique in agricultural research programs without the opportunity to waive this requirement, and changed the rules for those seeking grants this year in the middle of the application process—and the middle of their budget cycle. This has led to a number of valuable projects that made it through the first round being withdrawn from consideration due to the inability of the applicant to quickly come up with the 100 percent match. This includes several projects important to tree fruit growers such as myself.

We request that you work with your Senate counterparts to fix this drafting error without further delay so that these, as well as future, valuable projects are not lost.

There are other important programs within the research arena that benefit our industry, including the Technical Assistance for Specialty Crops Program that provides resources to address sanitary and phytosanitary barriers to trade. Our industry has utilized this program several times, most recently to develop pest lists for Myanmar to keep this market open for apples, pears, and cherries.

The IR–4 program, which supports research to facilitate the registration for crop protection tools for minor crops, is also valuable. Registrants often choose not to expend the resources to register a product for a specialty crop, where the market for that product is much smaller than for major commodities grown on more acres.

The Agriculture and Food Research Initiative and the Organic Research and Extension Initiative are two additional competitive grant programs that serve as a resource for addressing grower challenges.

Research means nothing without a focused effort to get the information discovered into the hands of growers. Federal formula funds provided to universities for research and extension activities through the Hatch Act and Smith-Lever Act have eroded over the years. This has created a void in this critical last mile of allowing agricultural research to be applied on a broad scale. We encourage you to reinvigorate Federal investments into extension activities.

Agricultural research is like a three-legged stool—it fails to fully achieve its purpose without the investment and support of industry, the Federal Government, and the university/extension system. The success of this model is exemplified in Washington state, where ARS scientists work across the parking lot from WSU scientists, who both go to the Washington Tree Fruit Research Commission and other commodity organizations for funding of individual projects.

It is a challenging time to be a tree fruit grower. We are facing new trade barriers in key export markets. Labor, which is our largest input cost, is becoming exponentially more costly and difficult to find year-after-year. Pest and disease pressures certainly aren't getting any less challenging, while the rapid growth in specialty varieties of apples with different sets of characteristics that respond differently to these pressures further complicate the scene. Our growers do not ask for direct subsidies. Investment in research is key to ensuring that we can continue to provide top-quality, American-grown apples, pears, and cherries to consumers both here in the U.S. and around the globe.

Once again, I would like to thank the Subcommittee for giving me the opportunity to testify before you today on the research needs of growers like myself when it comes to resiliency and mitigating risk. I am happy to answer any questions you may have.

Mr. COX. Thank you so much, Mr. Godwin.

And, Dr. Gmitter.

STATEMENT OF FRED G. GMITTER, JR., PH.D., PROFESSOR, HORTICULTURAL SCIENCES, CITRUS RESEARCH AND EDUCATION CENTER, INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES, UNIVERSITY OF FLORIDA, LAKE ALFRED, FL

Dr. GMITTER. Good morning, Chair Plaskett, Ranking Member Dunn, and Members of the Subcommittee.

I am Fred Gmitter, a Professor in Horticultural Sciences at the University of Florida. I am pleased to be here today to testify on behalf of the University of Florida's Institute of Food and Agricultural Sciences.

For more than 30 years my major area of study and research has been the genetic code of citrus trees and fruit.

I have no doubt that today plant breeding is one of the most important and powerful tools at our disposal to combat global challenges in agriculture and food production.

Over the years I have seen a dramatic increase in our knowledge of plant biology and genetics that enable us to better understand what makes a plant do what it does in response to various environmental and man-made stressors.

This information is what has enabled us to develop new, innovative breeding tools like gene editing. It is these new tools that also will enable us to capitalize on the tremendous investment into the knowledge base we have already developed to improve plants in ways that were just a dream when I first began to work in this field.

As temperatures rise, pests and disease evolve and spread, and natural resources become scarcer, we need to develop new varieties that are resilient to these emerging threats.

In my State of Florida, the citrus industry has been devastated by citrus greening disease, and production has been dramatically decreased by 75 percent in less than 15 years. We are running out of time.

Citrus growers need long-term sustainable solutions. There is no question that plant breeding innovation holds the key. Using gene editing, my team and others are working right now on developing citrus trees that are resistant if not immune to citrus greening disease.

Innovation is enabling us to potentially do in just years what would previously only have been possible in decades or longer, and with the rapid spread of citrus greening disease in the U.S., and in the world, time is a luxury that we don't have.

Scientists are now using gene editing technologies to precisely duplicate many naturally-occurring mutations, but to do so in elite plant varieties and in a relatively rapid fashion.

For example, to develop heat-tolerant lettuce that may be grown in the Central Valley of California, even with increasing temperatures; to develop potatoes that don't turn brown to decrease food waste which accounts for seven percent of the annual global carbon footprint; to develop crop plants with deeper roots that can sequester carbon from the atmosphere and keep it deep in the soil after harvest; to develop rice that can be grown with saline irrigation water or even under dry conditions, just to name a few.

However, for these and many more real-world benefits to be fully realized and widely adopted across breeding programs of all sizes and sectors, developers need clear science-based policy direction.

I am pleased that USDA in its new proposed rule on agriculture innovation policy, recognized that applications of gene editing can result in plant varieties that are essentially equivalent to varieties developed through more traditional breeding, and in those cases, it only makes sense that they should be treated in the same way from a policy perspective.

Historically, under the Coordinated Framework for Regulation of Biotechnology, USDA, FDA, and EPA have each served a specific function in ensuring the health of our food and the environment. We encourage the U.S. Government to ensure alignment in risk-based policies around plant products of the newer breeding methods across these three Federal agencies, and I appreciate the Executive Order announced just yesterday which seeks to accomplish that.

Any lack of consistency among the agencies will stifle research investments and activity and prohibit widespread access for public-sector scientists to these evolving tools, and the array of critical benefits they hold for society now and in the future.

It is also important that the U.S. continues to take a leadership role in driving consistent plant breeding policies at the global level. We must continue moving forward in supporting research and plant breeding solutions to solve our collective global challenges.

With that, I will be happy to take any questions you have, and thank you for the opportunity to speak.

[The prepared statement of Dr. Gmitter follows:]

PREPARED STATEMENT OF FRED G. GMITTER, JR., PH.D., PROFESSOR, HORTICULTURAL SCIENCES, CITRUS RESEARCH AND EDUCATION CENTER, INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES, UNIVERSITY OF FLORIDA, LAKE ALFRED, FL

Good morning, Chair Plaskett, Ranking Member Dunn, and Members of the Subcommittee. I am Fred Gmitter, a Professor in Horticultural Sciences at the University of Florida and I'm pleased to be here to testify on behalf of the UF Institute of Food and Agricultural Sciences.

For more than 30 years, my major areas of study and research have been the genetic code of citrus trees and fruits—the genes that determine how the fruit tastes, smells, looks, and how the tree responds to pressures like disease and pests—and using that knowledge to develop improved citrus trees and fruit. I have no doubt that, today, plant breeding is one of the most important and powerful tools at our disposal to combat global challenges in agriculture and food production.

Also, over those years, I have seen a dramatic increase in our knowledge of plant biology and genetics that enable us to better understand what makes a plant do what it does in response to various environmental and man-made stressors. This information is what has enabled us to develop new, innovative breeding tools like gene editing; and it is these new tools that also will enable us to capitalize on the tremendous investment into the knowledge base we have developed, to improve in ways that were just a dream when I first began to work in this field, the plants that serve all humanity.

As temperatures rise, pests and diseases evolve and spread, and natural resources become scarcer, we need to develop new varieties that are resilient to these emerging threats. This is what plant breeders have been doing for centuries: combining genetic knowledge with plant breeding tools to improve seeds and plants for better crops for the benefit of our environment, our health, and our food.

With the rapid development of environmental threats, diseases and pests, we are up against the clock. Long-term, sustainable food production requires continued application of innovations, like gene editing, that allow us to develop more resilient plant varieties.

An increasingly warming climate means an increase in: disease intensity, mutation rates, and the range of pests and diseases in areas where they formerly didn't exist. In my State of Florida, the citrus industry has been devastated by citrus greening disease, and production has been dramatically decreased by 75% in less than 15 years. We are running out of time. Citrus growers need long-term, sustainable solutions. There is no question that plant breeding innovation holds the key. Using gene editing, my team and others are working right now on developing citrus trees that are resistant, if not immune, to citrus greening, and the bacteria that causes it and the insect that spreads it. Innovation is enabling us to potentially do in years what would previously only have been possible in decades, or longer. And with this rapidly moving disease, time is a luxury we don't have.

The University of Florida is engaged is a number of other research initiatives directly related to mitigating the impacts of climate change. AgroClimate is an innovative web-resource for decision-support and learning, providing interactive tools and climate information to improve crop management decisions and reduce production risks associated with climate variability and change. Developed by the Southeast Climate Consortium, AgroClimate is a coalition of eight universities including: Florida State, University of Florida, University of Miami, University of Georgia, Auburn, North Carolina State, Clemson University and University of Alabama-Huntsville.

The Decision Support System for Agrotechnology Transfer (DSSAT) is a software application program that comprises crop simulation models for over 42 crops, as well as tools to facilitate effective use of the models. DSSAT and its crop simulation models have been used for a wide range of applications at different spatial and temporal scales. This includes on-farm and precision management, regional assessments of the impact of climate variability and climate change, gene-based modeling and breeding selection, water use, greenhouse gas emissions, and long-term sustainability through the soil organic carbon and nitrogen balances. And these are just a few . . .

Outside of Florida, researchers are using cutting-edge plant breeding methods to develop new water-efficient varieties of crops. With 70% of the world's freshwater used for agriculture, reducing the amount of water needed to grow food could have a significant environmental impact. In California, lettuce struggles in the heat. But researchers have found a wild variety of lettuce that is capable of germinating at high temperatures in the Central Valley of California—a useful characteristic given warming global temperatures. Using gene editing they have shown that it is possible to develop lettuce varieties that have the same heat tolerance as their wild relative, with the same taste and nutritional value as the lettuce we enjoy today.

Salinity in irrigation water is a major factor limiting the production of rice, a globally significant food crop. Gene editing has been used to develop rice lines that can be grown using saline water, with no changes to any other genes and no deleterious changes on any other aspects of plant yield and performance; this result was achieved in 1 year, where it could have taken a dozen years or more to accomplish this by conventional breeding. Work is underway to address drought tolerance in rice as well. With decreasing land and water resources available to meet the future needs of humanity, such changes become critical for our future.

Another area where researchers are working is in food waste reduction. In 2007, the global carbon footprint of wasted food was 3.3 billion tons—about 7% of greenhouse gas emissions, according the U.N. Food and Agriculture Commission. Plant breeders are using gene editing to develop new crop varieties specifically designed to cut the amount of food wasted. By making a small change to a potato's DNA, for instance, researchers will be able to make it less likely to bruise and brown. The new characteristic could eliminate 1.5 billion pounds of wasted potatoes.

Innovation is also key to the ability—and in fact, the necessity—to grow more food on less land, using fewer inputs. For example, using gene editing, scientists can develop higher-yielding crop varieties—from vegetables to corn and soybeans. These new plant varieties could produce more food, without additional inputs. The result: farmers can grow more food on less land, and in many cases on lands once deemed marginal for food production. Potentially this can also slow the rate of global deforestation, and thereby put the brakes on increasing CO_2 levels by sequestering more carbon.

And speaking of carbon, researchers are even looking at solutions to develop plants that can reduce carbon pollution. Naturally, plants take carbon out of the atmosphere and release oxygen through photosynthesis. A key to controlling carbon pollution could be to train plants to suck up just a little more CO_2 and keep it longer.

Scientists at the Salk Institute in San Diego are looking to do just that, by engineering crops to have bigger, deeper roots made of a natural waxy substance called suberin—found in cork and cantaloupe rinds—which is incredibly effective at capturing carbon and is resistant to decomposition.

The roots would store CO_2, and when farmers harvest their crops in the fall, those deep-buried roots and the carbon they have sequestered would stay in the soil, potentially for hundreds of years. Thanks to innovation, we could see real-life climate-change-fighting plants in our future!

These are just a few of the many examples of the tremendous investment by public and private-sector plant-scientists around the world in research across a wide variety of crops—with groundbreaking potential.

However, in order for these benefits to be fully realized, and widely adopted across breeding programs of all sizes and sectors, developers need clear, science-based policy direction. This is why we appreciate the recognition of USDA, in its new proposed rule on agriculture innovation policy, that applications of gene editing can result in plant varieties that are essentially equivalent to varieties developed through more traditional breeding methods. And in those cases, it only makes sense that they should be treated in the same way from a policy perspective.

Historically, under the Coordinated Framework for Regulation of Biotechnology, USDA, FDA and EPA have each served a specific function in ensuring the health of our food and the environment. We encourage the U.S. Government to ensure alignment in risk-based policies around plant products of newer breeding methods across these three Federal agencies. Any lack of consistency among the agencies will stifle research investments and activity, and prohibit widespread access to for public sector scientists to these evolving tools and the array of critical benefits they hold for society now and in the future.

It's also important that the U.S. continues to take a leadership role in driving consistent plant breeding policies at the global level. Late last year 13 countries, including the U.S., joined together in signing an International Statement on Agricultural Applications of Precision Biotechnology. This was a strong and encouraging show of support by governments around the world in recognition of plant breeding innovation, and the critical role that it will play in ensuring a more sustainable and secure global food production system.

In order to maintain the United States' position as an economic world-leader in innovation, it's critical that we continue moving forward in supporting research in plant breeding solutions to solve our collective global challenges. With that, I'll be happy to take any questions you have. Thank you.

Mr. COX. Thank you all so much for your testimony on this very important topic.

Now, Members will be recognized for questioning in the order of seniority for Members who were here at the start of the hearing. After that, Members will be recognized in order of arrival.

And, with that, I will recognize myself for the first 5 minutes, and so, but just give me 1 second here.

My district, the 21st Congressional District of California, is successfully the top agricultural district in the top agricultural state, and like so many producers all across our country, the farmers and ranchers in my district are currently dealing with: first, increased trade uncertainty; second, continuously shrinking labor pool, and giving those existing pressures you put on top of that a changing climate and/or natural disaster that is driven by climate change. You have seen that certainly in California and throughout the nation this year.

Really, the question gets down to the producers and what effect do all those pressures, particularly the climate change, are going to have on a producer's ability to remain profitable.

And, Mr. Godwin, I think you probably can speak directly to that.

Mr. GODWIN. Yes. There are a lot of things that we can't control as farmers, and you appreciate those every day. Climate is one of them. But we do things and we have learned to do things to help ourselves.

For example, this year on our farm we are installing our first 8 acres of nets covering a commercial crop, so we are doing that to control the sun and the impact of sunburn on fruit, as well as to mitigate potential hailstorms. And in addition to that, we are adding side curtains to keep pests out of the crops, and we are working with our local university to actually do some beneficial insect release within the nets to see if we can control environment within the nets without pesticides, as an example, or any chemical for that means.

Those are the kinds of things that we are doing. The unfortunate part is that these types of things are very expensive and there is not enough research right now to really validate, so it takes a kind of a good faith effort and a jumping in and really being committed at this point, because it is a lot of money. To cover an 8 acre field is a tremendous investment.

Mr. COX. Very good. And certainly on the organic portion of it, side of it, Ms. Tencer, do you have any comments on that?

Ms. TENCER. I would just echo that the—there is—oops. Thank you.

I would just echo that there is a risk of new practices and sometimes we see with new practices which are able to provide resiliency and the ability for producers to adapt, there may be up-front costs. Sometimes those costs pay off economically for producers in their yield or stability, but sometimes those payoffs may not be seen for another 5 or even more years down the line, and so there are some real challenges with being able to make those long-term commitments to those practices.

I would say the other thing that we have seen is that if you implement a single practice, whether that relates to your cover crop or your rotation or some of these additional techniques, as Mr. Godwin mentioned, you don't see the same success rate in terms of adaptation and risk management as you do with a portfolio of practices, and that again can be both complex and sometimes there are up-front costs. We really support the research, education, and extension efforts to help producers be most efficient in choosing that suite of practices.

Mr. COX. Thank you. And, Dr. Gmitter, you were talking about utilizing science to directly confront the challenges of climate change for some of these crops, and if you could reiterate some of the techniques and things that you are doing?

Dr. GMITTER. The biggest focus of our work these days is citrus greening disease, and this in some ways is a consequence of the movement of pests and diseases that they carry into places where they didn't exist previously, and so this is a very important thing for us.

I witnessed some hurricane damage three seasons ago on the Indian River area, the east coast of Florida, where some groves were under water for 7 days, and we had a root stock trial, trying different kinds of root stocks that happened to be planted in one of these places, and as we went back a month, 2 months, and a year afterwards we saw very clear genetic differences. Certain root stocks survived the flooding for 7, almost 10 days in some locations, and others did not, and so these are the kinds of things that as a plant breeder, we look at the totality of the needs of the industry, and although we are primarily focused on citrus greening disease, we have to look at all of these other factors, and this is just one example of the kinds of things that we see and we are learning.

Mr. COX. Well, thank you. And, Dr. Wolfe, recently this Committee held a hearing expressing the valuable role public research plays in ensuring the ag community is well-equipped to address these challenges, pests and disease, and now we are talking about protecting operations against climate change.

And I guess the question is, how do we best share the information with farmers so they are best able to protect their livelihoods from these risks?

Dr. WOLFE. Yes, as I mentioned in my initial comments, there is a real need for real permanence to hubs or centers where farmers can get that information reliably and we can build the materials available for farmers in terms of resources, but also developing real-time decision tools that they might have such as phone apps on their farm and that sort of thing, and do a lot of synergy working with farmers and with researchers to provide that sort of thing for them.

And right now a lot of land-grant universities as well as the USDA, *et cetera,* have developed some of these but there is a lack of permanence and real long-term funding for them. A lot of work can go into developing a great source for farmers to get this information, great way of getting the communication back and forth, and then, but they are dependent on soft funding, so that is a very important area.

I want to mention one other thing. You mentioned labor and I am thinking of horticultural crops, fruit and vegetable crops. It is so labor intensive, as you know. A single farmer might have hundreds of people they have to hire, and climate change is interfering with the timing of planting and harvest and so farmers are more challenged with the timing of when they, those labor force appears, *et cetera,* and it is a big challenge for our specialty crops.

Mr. COX. Well, thank you so much. With that, we will recognize the Ranking Member from Florida. Mr. Dunn?

Mr. DUNN. Thank you, Chairman Cox.

Dr. Gmitter, can you discuss what role biotechnology may play in addressing citrus greening? You had begun to do that. You have touched on that, but we had the opportunity to speak before the meeting, and I am not sure that people realize just how long this has been a problem for decades and decades around the world, and you have experience looking into all that. I wonder if you would address that for a minute or 2?

Dr. GMITTER. Yes. Citrus greening is a disease that has been known for more than 100 years. In Florida we have been living with it for more than 15 years.

Citrus breeding is a slow process. We are working with plants when we make crosses that take 5 to 7 years before they set their first crop of fruit to evaluate, so it is a very slow process.

It is further complicated in the case of sweet orange and grapefruit in that all of the sweet orange varieties that we know in the world, all that arose from mutations. That is to say, they weren't created by crossing things. They are mutations from some ancestral form, and the market is focused on orange juice or grapefruit, and grapefruit has the same story. We can't very easily use conventional breeding to bring in changes to these crops.

However, as we look at the range of genetic diversity that exists in citrus and we find types that are more tolerant to this disease, we can understand the genetic control in those plants, look into the sweet orange plant genome itself and find the same sorts of genes that we need to slightly change the spelling of the order of the nucleotides to make a plant go from something that is very sensitive to something that is tolerant and perhaps even resistant to the disease.

Mr. DUNN. Outstanding. Also, I wonder if you could address some of the other pest and disease threats that affect us. I am interested obviously in Florida, but let us not be too parochial if you have other areas in fruits that you are studying. I would like to hear that.

Dr. GMITTER. Well, there are a number of citrus diseases that we have lived with for many years. Our growers these days would be very happy to go back to the days when those serious diseases were the only problems they had to deal with, because they would impact production to the five to ten percent, 20 percent range, as opposed to something that is really knocked 75 percent of our production away.

Citrus tristeza virus is an important disease. Citrus canker was a very important disease that the Federal Government spent millions of dollars attempting to eradicate in an effort that failed ultimately because we had hurricanes that came and blew the disease all over the rest of the State of Florida.

Citrus canker is a disease that can be more easily addressed by genetic approaches. There is a number. I could give you a seminar that would take a day long to go through all the disease problems we have.

Mr. DUNN. Unfortunately we only have 2 more minutes, sir.

Just yesterday President Trump signed an Executive Order to streamline the agricultural biotechnology regulations in an effort to harmonize the FDA, the Department of Agriculture and the EPA. Can you elaborate a little bit on how important that is? You did mention it in your testimony and I want to drive that point home.

Dr. GMITTER. Well, that is critical and from my own perspective it is especially critical for specialty crops, things such as apples, pears, and citrus, because you have a small army of public-sector researchers, plant breeders, plant pathologists who are working on these crops that don't get the attention of the large companies like Monsanto/Bayer and so on. They are not particularly interested in those crops.

And as we are looking at using some of the new breeding technologies in these plants, the question becomes in my mind and many other researchers, "Well, if we are successful, are we actually going to be able to have an impact in these industries?" There are smaller industries as researchers we're smaller guys as well, and we don't have $15 to $35 million to deregulate some particular modification that we have made.

It is very important for us that there is harmonization and we would hope the harmonization would be on a science-based risk-based analysis of what the technology is and what it can accomplish and what it means to our industries.

Further, globally we have to look to the Federal Government to work with us so that on a global basis there is a more common understanding of the nature of what we are doing and what it means.

Mr. DUNN. Well, I thank you very much for that, Dr. Gmitter. I am going to say, I had a chance to review your biography before this hearing, and I was surprised and pleased to see that you actually had the patents on more than six varieties of citrus trees, so I applaud your innovative and industrious career, and we certainly look forward to you and your colleagues saving our citrus industry.

And with that, Madam Chair, I will yield back.

The CHAIR [presiding.] Okay. Thank you all.

I had a couple of questions, and of course, Ms. Tencer, in your testimony you note that research is only the first step, and you went on to say that farmers need continued education, training, and technical assistance.

What methods are most effective in sharing scientific advancements with farmers and ranchers, and what messages resonate the best with producers related to resiliency and risk mitigation?

Ms. TENCER. Thank you for the question.

In our most recent survey of certified organic producers around the country, they stated that they are going to other farmers, then their certifiers, and then their public universities third in terms of resources that they go to, but organic producers around the country would like to increasingly rely on the same sources of information, extension agents, NRCS personnel, even the risk management field staff to better support and disseminate those research needs.

We are really pleased to see progress in all of those areas, the new farm bill language supporting training of risk management agents in organic practices, NRCS is taking new initiatives to better train their staff in organic practices, but there is still work to do, in particular with extension service.

We think there is a lot of progress yet to be made both in terms of overall investment and in making sure that we have expertise in every, every part of the country in organic systems because it is inconsistent, and farmers get frustrated when they go to their extension agent and they can't help them with their organic suite of practices.

The CHAIR. Well, moving to an extension agent, Dr. Godfrey. I am putting you on the spot here.

What lessons have you learned with the drought, hurricanes, and now drought again? What lessons do you think have been learned that can be applied broadly to how U.S. agriculture industry will respond to the changing climate?

Dr. GODFREY. Adaptation to the changing climate is something that especially in the Virgin Islands our farmers are going to have to deal with probably on a little more frequency than other locations throughout the country, and some of the aspects of adapting to that can apply across the board, having resources in place for dealing with the aftereffects.

That has been a big problem for us, primarily because of our location. We can't stockpile materials. We don't have a lot of local resources, as I mentioned in my testimony. Our food is imported, our support supplies and support materials are all imported and it is difficult to have those things in place to help with immediate recovery.

And some of that deals with access to finances to get these materials and supplies by farmers, whether it is through Federal or local government-funded programs. There are issues with getting into those programs, getting those funds in place in a timely manner, and dealing with the aftermath. The devastation we received from the local hurricanes, those two back-to-back hurricanes, really impacted our local infrastructure in finding support for everything involved, agriculture, the community in general, our education system, hospitals, and everything.

There are a lot of things that we just don't have the capital and the capacity to have these things in place that we need after the fact.

The CHAIR. Well, I know that some of that is geographic, but how much would you say, and what are the specific ones that are related more to just being small-scaled farming? Because you talked about farmers farming in less than 5 acres as opposed to other places where potentially organics may be pretty much smaller in scale than some of their partner or larger scale, more conventional farming. What are the particular issues that those small-scale farmers face throughout the country that are not resonating or are not the same with larger-scale farming?

Dr. GODFREY. Right. Yes. Small-scale farmers have the issue of any kind of disaster, whether it is drought, floods, hurricanes, freezing, whatever can impact their whole crop.

The CHAIR. Yes.

Dr. GODFREY. Whereas a large-scale, they can absorb that. They have buffers because of their size. They can lose a portion of their crop and still survive and make it work out, where small-scale farmers, and especially they do a lot of monoculture, they are growing one crop and disease or an environmental event can come through and wipe that out and then there is no rebound, nothing left for them to fall back on. They have to start over whereas larger-scale farming, they do have that resiliency built in just because of their physical size. Any event is not going to impact their total crop. It may be portions of it, so they will have something to harvest and sell, whereas small-scale farming they just, by definition they just don't have a lot of resiliency built in because of their limited space and number of crops they are growing.

The CHAIR. Mr. Godwin, can you say, what are some of the practices that you may have in place to increase resiliency and mitigate risk as an actual grower yourself, and where would you think there should be additional support for that?

Mr. GODWIN. Well, it is a very good question. I know our strategy on the farm when I came back from the city to become a farmer again, we started with a 20 acre orchard, and we have developed and added other orchards and I like to say we put the farm back together, because we live in a narrow valley and it was owned by lots of different people and we, as neighbors retired and left, we have been able to add stuff back together to reach critical mass.

There is advantage to growing multiple crops and that is why we grow apples, pears, and cherries. It is not an accident. It is to mitigate the risk because all crops cycle differently and that gives you some benefit.

It also is important because it lets you start to spread some of your cost, whether it is equipment or computer systems and networks and monitoring that is available now with technology. It helps you to afford access to some of that technology, because as you grow you have a broader base to spread that cost on.

But at the end of the day what I see is that getting larger means it takes more investment, it takes more time, and it is a lot more work. And so, yes, you get some risk but there are always problems, so you think, "Well, I am going to mitigate risk by having three crops. That means I should do really well on the good years." In 19 years now of farming there is always something somewhere that takes a hit.

The CHAIR. Thank you. Thank you very much.

At this time I would ask my colleague, Mr. Baird of Indiana for your questions.

Mr. BAIRD. Thank you, Madam Chair, and we really appreciate you and Ranking Member Dunn for holding today's hearing. And I want to thank all of our witnesses for being here today.

As a Member of this Subcommittee and as well as the House Space, Science, and Technology Committee, I care deeply about the leadership that we have, U.S. leadership, in research and technology, and I am grateful we are discussing what our farmers need to address the challenges we have heard about here today.

It is estimated that by 2050 we will have a need to feed an additional two billion people, and we can agree that we want to do that and meet that challenge in a way that is good for our environment and is sustainable by our farmers.

My question comes down to the issue that I believe the United States must be a leader in agricultural technology including biotechnology, both to keep our environment healthy as well as to feed our families, but also for our economic and national security.

My question is, are we at risk of falling behind other countries in terms of agricultural research and technology related to resiliency, and if you feel that is true, are there any areas that we should be focusing our energy and research on?

Dr. Gmitter, we will start with you. I have only got 5 minutes, so we will see how far you go with that.

Dr. GMITTER. I will try not to go too far.

Mr. BAIRD. Okay.

Dr. GMITTER. There is no doubt in my mind, and I, again, I speak from personal experience. I have had a long-term relationship with one of the most important research universities in the area of citrus in China for nearly 30 years, and 25 years ago, 20 years ago, it was very common for my colleagues to send graduate students and post-docs to my lab to work together with us so we could accomplish things together, but more importantly for them to learn the technology that we have.

I was invited to the 120th anniversary of this university just last year, and to see the effort and the number of people and the resources that are devoted to citrus breeding and genetics in that university, which went from very primitive to where it is today, is astounding. We look at it and we say, "How can we possibly compete with this, not only in putting out academic papers but in getting real world results."

I have definitely seen in my lifetime, in the short period that I have worked, a real change in what the level of support is in other countries, and that is my crop, that is my business, my world, and it is probably the same I would bet in many other commodity research areas.

Mr. BAIRD. Thank you. Do any of the other witnesses care to say or make a comment?

Dr. GODFREY. Yes. I would like to mention that the land-grant university system in the United States is the envy of the world for agriculture research and community outreach, and it is a model that other countries look at with envy and try and develop in their own countries. We have been the benefactors of that since 1862 when it was first started at the land-grant universities.

And there are non-land-grant universities in the country as well conducting a lot of good agriculture research, but the partnership between the Federal Government and the local governments in the land-grant system to enhance research, community outreach, training the next generation of scientists to bring efforts forward to solve our problems and address issues such as sustainability and climate change, are some of the best we can see around the world, and people come to us for information, faculty, students, and modeling the program after the land-grant system.

Really, a lot of us in this room have benefitted from that over the years. I know I have personally. I have come up through my graduate and professional careers in a land-grant system and it has been a great benefit.

Mr. BAIRD. Anyone else?

Mr. GODWIN. From a farm perspective the two things that I worry about is the soil, rhizosphere ecology and improving that understanding of what is happening under the ground, and then the genetics and genomics and plant breeding. I think those are clearly two areas that we need more activities.

Dr. WOLFE. Well, I would just add I just recently had a whole contingent of researchers from the Chinese Academy of Ag Science come into Cornell to hear about what we are doing on climate change adaptation and mitigation here and also soil ecology and soil biology.

On the other hand, I have also been there with exchanges and they have, as was mentioned earlier, amazing advances from 20, 30 years ago, very sophisticated field research equipment and technology and all of that.

I think our outreach system is still excellent here and we have a lot going for us.

Mr. BAIRD. Thank you. I am out of time, but I did appreciate, Dr. Godfrey, you mentioning the land-grant universities, because Purdue University is in my district, so thank you.

The CHAIR. Thank you. At this time I will call on my colleague, Mr. Brindisi of upstate New York.

Mr. BRINDISI. Thank you, Madam Chair, for calling on me. Thank you to all of our witnesses who are here today, especially Dr. Wolfe. Thank you for being here representing Cornell University, a very important institution to upstate New York and to farmers across my Congressional district.

This question really is for all of our witnesses, whoever wants to take a crack at it, but reports indicate that as USDA considers moving research out of the Washington, D.C. area, Economic Research Service employees working on politically sensitive topics are being asked to relocate in high numbers, meaning there is a good chance they might leave the agency and decide to take their talents elsewhere. I am concerned that important topics like impacts of climate change won't be fully understood and recognized if we don't have skilled staff within these agencies doing this work.

Are you concerned that research on topics like climate change will be negatively impacted by this proposal?

Dr. WOLFE. I might take a first crack at that, and I mean, it has been a fantastic partnership for all of my career working with various USDA agencies, and they have also funded much of the work in soil health and also climate change from the SCRI Program to NIFA and Hatch Act funding, *et cetera.*

And my partners there, we just work hand in hand and it is so important to us, and I really appreciate talking to them because they also understand what is coming from the Department of Agriculture, the U.S. Department of Agriculture, because they are right here in Washington, and it is really useful to know what is happening in terms of policies and actually keeping us informed about that. If they were disengaged from the Washington, D.C. area, that avenue of information, for myself. I would miss that help in understanding better the initiatives that might be coming down through the USDA in the Department.

Also, the Washington, D.C. area is kind of a neutral ground in terms of commodities, and if people were to dissipate we might focus much more on the Midwest. I like the idea of keeping the USDA that has really got a very broad view of important commodities, and its being in D.C. helps that.

Mr. BRINDISI. Any of the other witnesses? Yes.

Ms. TENCER. I would just like to share that one of the challenges we have seen, particularly in the organic sector, is the need for research findings and trends about best practices to be well distilled and communicated to other Federal agencies, particularly looking at how the USDA's NRCS and Risk Management Agency understand the best practices in organic systems. And those have been challenging areas and there has been a lot of progress but there is still more to do.

Speaking from personal experience, I can say I have been invited over the years to go present and help facilitate information sharing across USDA agencies where we invite staff from various arms of the USDA to come sit together and talk and share what is happening on organic within their arms, and while USDA has always done a good job of inviting folks who were not based in D.C. to call in and listen, it was much more challenging for those USDA staff to hear, to engage in those conversations, while those who were in the room from RMA, NRCS, NIFA arms, *et cetera,* were able to more easily share information. We are a little bit nervous that that ability would be lost.

Dr. GODFREY. I would like to add the convenience of having the NIFA offices here in Washington, D.C. makes interacting with them much more affordable from an economic standpoint and accessibility to the people.

In fact, I have an appointment this afternoon with some folks at NIFA to discuss some of the issues for the Virgin Islands. Having them in this central location where we can combine efforts during a visit such as this Subcommittee hearing, meeting with NIFA, meeting with other colleagues and partners that we have, makes it much more practical and that partnership can be strengthened if we can meet in one location instead of having it distributed through different locations, with some of the NIFA people remaining here and some at a new proposed location. Just makes sense to have them all in one spot for us and interacting with other government agencies as well.

And from the Virgin Islands, it is relatively easy to get here from the Virgin Islands, but colleagues across the country, there are time and travel efforts that are involved in getting here, so you want to get the most bang for your buck.

Mr. BRINDISI. Thank you.

Madam Chair, I yield back my time.

The CHAIR. Thank you. Doctor, it is not easy to get here from the Virgin Islands. I am trying to convince everyone of all the hardship I have to go through traveling back and forth through the Miami airport, no less.

Dr. GODFREY. Sorry I blew your cover.

Mr. DUNN. But what a place to live.

The CHAIR. Yes. Yes. Getting there makes it worthwhile.

At this time I will call on my colleague, Mr. Thompson, for your questioning.

Mr. THOMPSON. Madam Chair, thank you very much. Ranking Member Dunn, thank you for having this hearing, and thank you for each of the panel that are here. I greatly appreciate it.

We know that it has quite frankly always been challenging times for those who grow our food, and for many different reasons but especially with climate. It is the history of it. It is the nature of agriculture, in fact, the form of our current Federal agriculture policy in the farm bill was a direct result of the climate disruption that we know as the Dust Bowl.

We know that the Irish Potato Famines where normally those potatoes do really well in kind of a cooler, maybe a little bit moist environment and when it gets to extremes which it did several times in history resulting in a million deaths when the temperature and the moisture got to an extreme level with the mold, water mold, that resulted in those famines.

In Statuary Hall, Iowa honors Dr. Norman Borlaug who was credited with saving a billion lives. At most it was, figure out the math, it is probably closer to two billion lives today by using science to adapt to the impact of changing climates.

Agriculture is science- and technology-based on necessity and it always has been, and yet we need more funding for USDA research. This Committee has done a good job, at least the past two farm bills I have been involved with, at supporting USDA, but we need the rest of Congress outside this Committee to recognize the importance of making that investment.

Where I look and compare what we fund, the National Institute of Health, and there is no criticism there, but quite frankly what they get this much and USDA gets this much and there is nothing more fundamental to health than good nutrition. It is what we take in, what we consume, and so I, part of what I would like to see is a better bridging, more collaboration with the folks at NIH that have been blessed with increased funding every year with the folks with USDA.

Dr. Wolfe, can you speak more on the importance of the role of cover crops in promoting healthy soils? I was proud to lead the first Congressional hearing we ever did on healthy soils a couple years back. And also, how do healthy soils facilitate the retention of moisture within the soil, which is really important obviously for folks impacted by drier climates?

Dr. WOLFE. Yes. Thank you for the question.

Yes, cover crops are one of the core methods of really rebuilding our soils, many of which have over time had organic matter depletion. And almost every farmer I talk to today is very interested in rebuilding that organic matter, rebuilding the health of their soils so that they are not passing on to the next generation soils that are not as good as they inherited from their parents.

Cover crops are out there. In addition to your cash crop you have fall/winter cover crops, you have more vegetation out there sucking up CO_2 from the atmosphere, which is the greenhouse gas, and putting it into the soil as organic matter and it is just one of the key building strategies.

Although, building the organic matter can take some time, but even in the first year of use of cover crops, if it is a year that we have heavy rainfall events, farmers see immediate benefits in terms of reduction of soil erosion which is a huge devastating consequence for farmers from heavy rain. It is one of the main strategies, also directly adding organic matter like manures and then also reducing tillage which can also lead to loss of organic matter.

So all of those are key strategies, and what is fascinating about this soil health thing right now is all farmers are talking about organic as well as conventional. There is really a bit of a revolution going on even. I see this worldwide. I do some work in East Africa, there, too, rebuilding soils, and it has this advantage for coping with climate change as well as providing better nutrition for crops, reducing other inputs, and also, by the way, storing carbon in soil playing a role in mitigation. It is a very important strategy.

Mr. THOMPSON. Very good. Pennsylvania and I assume New York based on some of your research you have been involved in, the anatomy of a wet year.

Dr. WOLFE. Yes.

Mr. THOMPSON. We are not really getting so much warmer as wetter.

Dr. WOLFE. Yes.

Mr. THOMPSON. There has been lots of rainfall. Any specific mitigation actions that you would recommend for farmers in our area, given sort of the pattern that we are in for the time being?

Dr. WOLFE. Yes. Well, relevant to your previous question, too, I mean, building healthy soils also affects the structure of the soil such that it drains better as well as holding water better, it buffers from both drought and flooding, so that is one strategy that it kind of builds some resilience. But still if you have very heavy rainfall events there are different strategies for drainage and all of that, also thinking about different timing of operations so that we don't have impacts on water quality. There is a whole range of strategies for dealing with that.

And when I talk to farmers about wet years *versus* dry years, they say a dry year comes and goes, I might lose something that year, but a really wet year, if I lose a lot of my soil, that is going to take a generation to replace. They are really concerned about that, and we have seen more of that than, 30 years ago we thought mostly about drought when we thought about climate change, and we are actually seeing that too much water is as big or bigger problem than too little at this point in time.

Mr. THOMPSON. I am sorry. Thank you. Thank you, Madam Chair.

The CHAIR. Thank you. At this time, the gentlewoman from Maine, Ms. Pingree, for your 5 minutes.

Ms. PINGREE. Thank you very much, Madam Chair. Thank you to you and the Ranking Member for having this hearing, and certainly to the panelists for being here. I really appreciated all of your remarks and testimony.

I have so many questions, but I am going to just keep it to a few.

Ms. Brise, thank you so much for the work you do. I know you know that I am very supportive of organic farming and organic research and it is really a vital role that you play. I am also a certified organic farmer, so I am well aware of these challenges, but one thing I just wanted to mention is that sometimes we think about organics as sort of this mysterious thing that happens with different kind of inputs and outputs, but basically the fundamentals are around soil health. This is an important moment in time, because as we have been talking about, there is so much focus now on soil health, and we have a lot to learn and a lot of sharing that should and could go on.

And, Mr. Godwin, I wanted to mention to you that I also sit on Agriculture Appropriations, and we have been working very hard on that specialty crop grant match that you talked about, so we are hoping that we can get some language in the bill. It doesn't help anybody if we get these bills passed by the end of September, but it is really important that you brought that up and for people to know it. It is also important for the entire Committee to understand the issue you raised here on ARS. There is no hiring freeze at the Department of Agriculture, but not a lot of positions are being filled right now, and this Committee should be particularly concerned, as we should all, about the importance of those people to do the work, and you made that really clear.

Dr. Wolfe, you have a wonderful career here in researching soil health, and many of the things that we are so focused on and that farmers are anxious to participate in more, and I know you were a little bit involved in some of the work that was going on in the New York Soil Health Program.

Dr. WOLFE. Yes.

Ms. PINGREE. We have a lot to learn from individual states. I am particularly interested in how farmers can participate in carbon markets. I see it as, of course, an important tool. It is good for the farmers and then it is also good if there is a potential for another source of income. And some of that was talked about in New York. I don't think it has moved forward, but in terms of looking to the states right now for what is going on, can you tell us just quickly about that, and I am particularly interested in how we are going to measure, what kind of metrics we are going to use so that we can understand how much carbon is being sequestered in the soil so that farmers can be paid fairly for what they are doing?

Dr. WOLFE. Yes, that is a complicated area and something, in New York, we have had a long history actually of farmers, pioneer farmers, working in that area of soil health on their own and then also working with Cornell and other agencies to do the appropriate research to back them up and move forward, and then also getting a lot of good input from our organic farmers who have been at that for a long time.

Yes, and with the interest and the recognition now that soil health is not just something that farmers are motivated about from the standpoint of building resilience and reducing inputs, but also can be part of the solution in terms of slowing the pace of climate change. A lot of work is turning that way and looking at that.

I actually have a project right now where we are trying to get some baseline data on soil carbon in our soils and that sort of thing.

We have one district of New York, an Assemblyperson in New York State who received funding for a pilot project, trying to look at ways we might compensate or incentivize farmers to adopt soil health in part for the benefits of this ecosystem service of storing carbon. It is tricky.

I actually head a USDA NIFA-funded project, and part of that was to look at low-cost approaches to monitoring.

Ms. PINGREE. Yes.

Dr. WOLFE. I have a graduate student who is still finishing up even though the funding has run out from that, worked on infrared spectroscopy, for example, even have on-the-go tractor-mounted spectrometers that can give you meter by meter estimates of the carbon in the soil. But even with those lower cost approaches, I do think monitoring farm by farm changes in carbon, it is the air bars around those measurements and the time it takes for that to happen, my personal opinion on approaches to this are focusing more on the practices that we know will build carbon in soils. Getting some baseline data on carbon in a region or a farm, then having a plan at different farms or for a region, how we are going to increase the acreage of farmers adopting practices, cover cropping, reducing tillage, using more organic amendments to get there, and tracking that acreage, and periodically perhaps every 3 to 5 years, maybe actually going in and seeing what progress this has made in terms of carbon.

There are also ways of discounting the incentives you might provide in case farmers, for example, for whatever reason they decided to till the heck out of their soil and all of a sudden the carbon is lost, you can discount the initial benefits. But, creating more incentives and educational information to get farmers moving in the right direction with practices.

Ms. PINGREE. Great. Well, I am out of time, but thank you very much for that. And you certainly have hit on the key question as to whether we are going to measure outputs or practices, and the sooner we can figure that out, the sooner the farmers can start benefitting from the markets that are going to continue to grow, thank you.

Thank you, Madam Chair.

The CHAIR. Thank you. The gentleman from Florida, Mr. Yoho.

Mr. YOHO. Thank you, Madam Chair, I appreciate you holding this hearing. I appreciate you all being here.

And as the debate on climate change goes on and up here in Congress how we can't solve like border security and things like that, I am going through the Old Testament right now and I notice there was drought, disease, famine, and pestilence, and what I have noticed is human nature has adapted and that is what you guys do in biotech, especially in the agricultural sector, is we adapt. We make better strains like Dr. Borlaug did that were drought resistant that could be more heat-tolerant.

As we move forward in the science of all this, do you believe that the use of biotechnology in agriculture, it is a pretty rhetorical question, will increase or decrease over the next 10 years? It will increase, right? I mean, we are going to——

Dr. WOLFE. Let us hope, yes. We need it more than ever.

Mr. YOHO. I am going to have to talk to my question writer. Moving on. As we use biotech, especially with Florida citrus, and Dr. Gmitter, you are doing fabulous work on that, we know some of the technologies to solve that problem and it is so critical for an iconic crop for Florida, because Florida without oranges is like Wal without Mart. They kind of go hand in hand or Bud without Weiser. It is imperative that we get a cure for this, and one of the things will probably be a GMO or CRISPR gene technology. Is that true?

Dr. GMITTER. It is very likely that that is going to be one of the things that is going to contribute to the solution and a major contributor to that solution.

It is interesting to hear the discussion about soil health and cover crops, and one thing that we see in Florida, which is basically a beach.

Mr. YOHO. Sandy——

Dr. GMITTER. Very, very sandy soils with minimal organic matter. One of the things that is happening in the meantime while we are waiting for long-term solutions is our citrus growers have paid an enormous amount of new attention toward soil health.

I know so many citrus farmers who are putting out compost, who are growing cover crops, and so all of this is, it is a complicated disease. It is going to take a complicated set of steps to put this all together, but clearly a genome edited solution is going to be a big part of that problem.

Mr. YOHO. And I appreciate you bringing that up, because what we have seen in the past and you are probably real aware of, the GMO for the papaya ring virus, spot ring virus, that the University of Florida worked on. They found a GMO that was tolerant of that virus, yet it took 12, 15 years to take that research to market.

The regulatory environment, how much does that impede incentivation for development and research but then to move a product from finding a cure to market? What needs to change in your realm with the work that you guys have done?

Dr. GMITTER. We really need to look at this on a scientific basis on what is the science. There is an awful lot of negativity about GMOs and I can understand some of that. What we are talking about with the newer breeding technologies; however, gene editing, we can accomplish things that would occur naturally spontaneously in nature, and it can be done in such a way because we have learned some new tricks in such a way that there is no footprint, no thumbprint, no fingerprint left behind. It is just a change in the DNA, the natural DNA of the plant.

Mr. YOHO. Natural selection, right?

Dr. GMITTER. Nothing that is brought in from an outside organism. There is no jellyfish. There is no bee. It is citrus. It is citrus DNA, and so this holds huge promise for us.

Mr. YOHO. Well, I hope you guys are involved in that process when it comes to the GMOs and the Internet, because we know the hundred Nobel laureate scientists said there were no negative consequences of the GMO. We need your voice out there educating the public of what a GMO or CRISPR gene technology is or isn't.

I want to move on to something that, and I sit on the Foreign Affairs Committee, too. What safeguards do we have in place to land-grants or all of our universities to protect intellectual property? And I bring this up because we had one of our professors at the University of Florida that was going on a sabbatical to China. I said, "What are you working on?" He goes, "Well, I am taking the research I have been working on over there." And I am like, "No, you are not, that is our intellectual property." And if you guys, I have 15 seconds if somebody wants to chime in on that.

Dr. GMITTER. I can hit that very quickly. Every variety that is released from the University of Florida plant breeding programs is protected by plant patents and it is protected abroad by plant breeder's rights, and as we find partners internationally to license things, we work with them. It is important to have an international partner involved with this because if we don't have a partner in a foreign country, you know what, citrus trees fly anyway.

Mr. YOHO. Right.

Dr. GMITTER. And the technology goes away, so it is important that we have a recognition of the importance, the significance of having a partner.

Mr. YOHO. I appreciate you all being here.

Madam Chair, I yield back.

The CHAIR. Thank you. Dr. Gmitter, I have a question for you. In your testimony you talked a little bit also about saline in water and irrigation and the usage of that in terms of rice. In the Virgin Islands we have huge issues with irrigation and desalinization plants. How is this science working in that and do you see real support, not just in rice crops and others, but that could be utilized in other areas as well?

Dr. GMITTER. Yes, it is interesting talking about foreign affairs. The paper that was published on this technology came from China.

The CHAIR. Yes.

Dr. GMITTER. And they found——

The CHAIR. We took their intellectual property?

Dr. GMITTER. I am sorry?

The CHAIR. We took their intellectual property?

Dr. GMITTER. I wouldn't say we have done that, no. The information is out there.

The CHAIR. Right.

Dr. GMITTER. The information is out there and maybe.

The CHAIR. Don't answer.

Dr. GMITTER. They found a single gene that modulates the plant's response to salinity.

The CHAIR. Yes.

Dr. GMITTER. And by knocking down the expression of this gene, they can water the plants with salty water and the plants grow normally. They found there were no other changes to any of the other genetics of the plant, and so this is the kind of thing that the scientific community as a whole were just beginning to scratch the surface.

We have a lot of information and understanding of some of the fundamental biology and underlying genetics, and if we can just simply change a gene in a very minor fashion, we can dramatically change the behavior of the plant. This thing about salinity in rice, those genes are actually in common in almost all plants. Very similar systems have evolved over the millions of years that plants have evolved. There are huge opportunities for that.

They are working also on genes that are involved with tolerance of drought stress. There are people now who think that we can grow rice in the same kinds of places where we grow wheat without flooding, and these are large globally-important food crops and this is the future that is ahead of us if we can find the appropriate way to get there.

The CHAIR. I see. Thank you so much. That is very informative. I am waiting for it to become changing the genetic disposition for the behavior of my five sons, my four sons, so that they would have a tolerance to homework.

Dr. GMITTER. Let the record show I raised my hands.

The CHAIR. Mr. Panetta of California, you are next for your 5 minutes.

Mr. PANETTA. Once again, thank you, Madam Chair, Ranking Member Dunn, and to all the witnesses, thank you for your time for being here today as well as your preparation in order to be here and all the work that you have done to become experts in this area. Thank you very much.

Obviously, everybody in this room would agree that agriculture and people in agriculture are uniquely positioned to contribute to the mitigation efforts when it comes to climate change, and I think that is why it is very, very important. I think all of us could agree why farmers, organic, conventional, need to be at the table when we talk about reducing our national greenhouse gas output and our footprint.

And so, Ms. Tencer, in your experience, obviously being from the Central Coast of California and understanding the balance and the work that our people in agriculture, be it organic or conventional, have taken I would say on the forefront in this area, what is your experience in working with either the organic or the conventional community when it comes down to the steps that those type, those producers, are taking to be proactive when it comes to climate change and dealing with the effects of climate change?

Ms. TENCER. Thank you. It is exciting to see that farmers of all types are innovators and experimenting on their farms day in and day out with diversity of practices, and what we are seeing again and again is that farmers who are implementing a variety of practices are having the most impact on both increasing their ability to adapt, as well as to mitigate greenhouse gas emissions.

We are seeing that reduced tillage coupled with the full suite of organic soil health practices, including crop diversification, cover cropping, organic amendments, and sound nutrient management, can really enhance carbon sequestration and build climate resiliency.

We are also seeing incredible innovations between farmers and researchers on how to adapt. I know we recently supported a project at the University of California-Davis, a researcher there, Emily Gowden, who was interested in how to help farmers deal with drought situations and worked with an organic tomato grower. And by changing their soil health practices, increasing their compost rates, and doing a few other soil health-related practices, they were able to reduce irrigational requirements by 6″ to 12″ per year without impacting yield. That is a really exciting innovation and on an organic farm with the supportive research to directly support growers' ability to adapt to climate change.

Mr. PANETTA. Definitely.

Mr. Godwin, have you worked with producers that have taken steps to deal with efforts, mitigation efforts, when it comes to the effects of climate change? And if so, what types of things are they doing?

Mr. GODWIN. Sure. Yes. Yes, I have, and we do some on our farm as well as other neighbors and friends.

One of the big things that we are doing for soil building is, I mean, farmers are simple, ingenious people. We do a lot of mow and blow, so we cut out holes on the side of our mower and we blow the clippings under the tree, as an example.

Where we farm organically, we have gotten away from herbicides and chemicals, so we are trying to grow the cover crops to the tree and finding cover crops that are low growing so they don't interfere with irrigation and tree growth, as an example.

And then there are some places where we incorporate biochar and other things to try to, again, change the soil biology to get favorable conditions.

Mr. PANETTA. Outstanding. And let me ask both of you, what here on this Subcommittee, and in that building across the way and within our Federal Government, what can we do to help support those types of efforts and to expand on it? What can happen here?

Mr. GODWIN. I think that the biggest area is making sure we have the smart people helping get the right research. There are snake oil guys that come by every day with new stuff with very little documentation and data, and so the right researchers and the right efforts happening, that is where the extension comes in and it is so important, because then it helps me make better choices because there is a lot of people selling a lot of stuff.

Mr. PANETTA. Well, fair enough.

Ms. Tencer?

Ms. TENCER. I want to thank the Committee because we did see some real gains in the most recently passed farm bill to further the field of research both in organics specifically, but in climate resiliency and adaptation more generally.

And we are really excited about that and there is still more to do. I would say that one thing is not looking at certain programs to address the full suite of challenges we face in both climate resiliency, adaptation, and mitigation. One program alone can't fix this all, but it really has to be integrated across various USDA programs.

And last but not least, we have more work to do as a community, and with your help in ensuring that research results aren't sitting on the shelves of academia but are translated and usable for producers across the country.

Mr. PANETTA. Thank you. And I thank the other witnesses for their leadership in this area.

And I yield back my time. Thank you, Madam Chair.

The CHAIR. Thank you. Ms. Schrier of Washington State, your questions?

Ms. SCHRIER. Thank you, Madam Chair.

I have had a lot of my questions already answered, so this is going to be a smattering of little detailed ones. This is what happens when you stay through everything.

Okay. The first is that I see this commitment from all of you because you are science-based and farmers, our smaller farmers, but you are committed to all of this. And yet, just yesterday I had a conversation with our Chairman, Collin Peterson, about this topic, and I got the impression that overall there was a ton of skepticism and feet dragging, so I just wanted to get your perspective.

If you look at farming across the country, what is the buy-in, what is the interest, where is the passion about soil health and doing these things? Is it only organic farmers? Is it only small farmers? Can you give me that sense? And I don't even know where to start. Whoever wants to answer.

Dr. WOLFE. I might start. I mean, I have been at this for 30 years and I do think it is changing as farmers are beginning to see changes on their own farms. Thirty years ago we had the climate models to talk about looming threats, but now they see so many changes so they are much more open to that.

In fact, there was a big, one of the biggest farmer surveys I am aware of, was done by a colleague, Arbuckle, at University of Iowa, I believe, Iowa State, and over 4,000 corn and soybean growers, and something like 67 percent said they felt climate change was happening. Not all of those were convinced that humans were the primary cause, but they are all convinced something is changing on their farm and they are interested in adaptation.

And actually another 20, 30 percent are kind of on the fence about it. Only a few percent said, "We just don't believe in it." I think the attitudes are changing as they are seeing impacts on their farm, that is one thing.

I think that also I don't know any farmers who aren't interested in renewable energy and what that might mean for the bottom line for them, and that is kind of relevant to all of this. You can go Iowa, and you see all the farms have their wind turbines up. This has to do with state and Federal policies that have helped facilitate this just like at the individual homeowner level. There has to be a way for them to break into that, that sort of renewable energy area.

So another area that has been kind of positive is a major mitigation strategy for farmers is reducing nitrogen fertilizers used, because it is not just about nitrate in waters, but also nitrous oxide emissions, which all of you would know, which is a very potent greenhouse gas. And, for example, at Cornell and other places as well, a colleague of mine has developed a phone app called Adapt In which allows farmers to reduce their nitrogen application levels without risk to yields. It is kind of been demonstrated over and over on farms.

Ms. SCHRIER. And one of the best ways, my understanding is one of the best ways to do that is to do no-till or low-till farming so you don't have erosion in the first place. You don't have to keep applying nitrogen. You can have more soil.

Dr. WOLFE. Yes.

Ms. SCHRIER. My question is, I think most farmers, probably a hundred percent of farmers should understand the climate is changing. Farmers really could save our planet. With soil health and with cover crops and crop rotation, farmers can decrease our greenhouse gas emissions and sequester carbon and take 20 percent out of our atmosphere.

Dr. WOLFE. Yes.

Ms. SCHRIER. That is what I want to know. Where is the interest? Is the interest there and what can we do? I don't think they want to hear from "Suburban Schrier" here about this; but, farmers learning from farmers like we heard from Ms. Tencer, having the researchers available, and the outreach programs, how do we make that connection happen?

Dr. WOLFE. There are still constraints to adaptation and adoption of practices, like most farmers are really quite convinced that they have seen enough pioneer farmers using soil health practices that are seeing benefits, for example, in a dry year, surviving quite well, whereas they are not. But, they have to purchase no-till farm equipment, new types of actual capital investments. There is more management complexity in using cover crops, so it is those kind of real challenges, and this is where it is just a matter of time and also farmer-to-farmer training. Those have been successful.

Ms. SCHRIER. Sounds like this is a place where we could help, with helping with financing that.

Dr. WOLFE. Yes.

Ms. SCHRIER. I have a couple questions. I am running out of time.

I had a question for you, Dr. Gmitter, about whether there are perennial wheats, perennial crops. You had talked about not having to till and some genetic engineering. I was wondering if there is anything on the horizon there?

Dr. GMITTER. I am sorry. Can you repeat?

Ms. SCHRIER. Perennial crops so that you wouldn't have to plant every year?

Dr. GMITTER. Yes.

Ms. SCHRIER. Anything on the horizon with genetic engineering?

Dr. GMITTER. Well, citrus is a perennial crop, so——

Ms. SCHRIER. You were talking in a grander scale, like you were talking about genetic engineering for rice to grow with saline, so this would be about whether those prospects——

Dr. GMITTER. Converting annual crops into perennial plants?

Ms. SCHRIER. Yes.

Dr. GMITTER. I am not personally aware of a whole lot of work going on in that area.

Ms. SCHRIER. Okay. And then last comment. I only have 10 seconds.

If you can get it in. There was some discussion of GMOs, and I just, in my mind there is a difference between GMOs where you are doing what you are talking about, taking some naturally occurring features and then reproducing them *versus* GMOs where you modify an organism to be resistant to a pesticide, for example, and then can cover a crop with a pesticide. I wondered if you could comment about the difference there? It seems like a very over-arching term.

Dr. GMITTER. Yes, it is a very simple distinction actually. In general, the GMOs that we look at are cases where genetic material is taken from other plants or other organisms and moved into the plants that we grow.

What we are talking about with gene editing is much different. It is simply doing something, and we have the technology to do it now, doing something with the plant's own natural DNA, which given an infinite period of time would happen naturally, but because of the way things are changing, we don't have infinity to wait.

Ms. SCHRIER. Thank you. Thanks for your work. Thank you, all of you.

Dr. GMITTER. Thank you.

The CHAIR. Thank you.

From the gentleman from New Jersey, Mr. Van Drew.

Mr. VAN DREW. Thank you, Madam Chair. And thank you all for being here today and taking the time out of your busy schedules to discuss the impacts of climate change on our farmers and what they can do to mitigate these risks.

Working with our extensions in land-grant universities, it is vital to the success of our producers across the country, and I know I am very proud, I am from New Jersey, of Rutgers University, what was Cook College and was the College of Agriculture Environmental Science, and now is the College of Biological and Environmental Sciences. And the reason I know, is that is where I graduated, but they have done a lot of good work with this as well.

And as we continue to deal with the climate change and its impacts, including changing weather conditions and rising sea levels, it is important we continue to meet the needs obviously of producers with advancement in research, new technologies and improved management; technology matters.

The question I have, and I don't mean to go back to this again, because I really read two different stories about this, and I just want to go back to it a little bit, and I don't want to be China-phobic because I am not, but they are really becoming a leader in the world in many, many areas and are very competitive with the United States in many areas as well. But do you feel that they are moving ahead at a faster rate, that they are competing more, that they do have the potential? As much as we love our land-grant universities and everything that we do, and it is all good, are we in a real competition here? Because there are folks absolutely in the agriculture world, and I have read some of your periodicals, that do believe it is really happening.

And any one of you can answer that.

Dr. GMITTER. May I, please?

Mr. VAN DREW. Sure.

Dr. GMITTER. There is no question that technologically the Chinese system is moving much more rapidly than ours is today.

Mr. VAN DREW. Okay, that is the answer I wanted.

With that being said, candidly is that because they are to some degree stealing our technology, utilizing our technology, our intellectual property? Is it just because they are investing so much in research and because of the system they have of government, they can control that so much? Which is it?

Dr. GMITTER. In my opinion, part of it is investment. It is financial and they are pouring a lot of money into equipment. They are sending their students not only to the U.S. but everywhere around the world to try and gather the best information that is available in the world of science. As scientists, we openly communicate and they are doing a good job at that.

One thing that has always been important in my mind where we have an advantage is even though these Chinese researchers, and I am speaking about citrus now specifically, but it probably is more broad. Even though they are racing ahead technologically, there is no connection, no connection really, between what goes on in the research laboratory and what goes to the field.

Twenty years ago I was invited and I gave a talk and we met with some important political guys and they asked us what can we do to help our citrus farmers in this province, and we said, "Well, you have excellent researchers here doing really good things, but you don't have any connection between what they are doing to the farmers." And this is an advantage that we have. We talked about the land-grant system and the ability to extend this information.

Mr. VAN DREW. Okay, to make sure I understand: The real advantage we have is, and I am familiar with it if I keep my voice here, is that we get our information out to the farmer. That is part of the thing. Farmers have questions, they call the universities, there are people who actually will come out to the farm, help you, work with you, train you, *et cetera,* so they are learning a great deal of information but they aren't getting that information to their farmer who is still farming in somewhat of a traditional way?

Dr. GMITTER. That is a part of it, but another part of it is you have researchers, and I am an example of that. I don't have an extension appointment, but I interact with citrus farmers all the time, nearly 30 percent of my time goes that way, and it is because I need that information from them for me to structure the research that I do to provide benefits to them. There is a good two-way communication as opposed to a vacuum between agriculture and researcher.

Mr. VAN DREW. They don't have a two-way street? What are they doing with all this information they are learning?

Dr. GMITTER. A lot of it becomes publications and the researchers are rewarded for publishing in high-level international journals, and there is little recognition or reward, at least in the world of citrus, for any of that getting translated to something that helps agriculture.

Mr. VAN DREW. It is really not practical, actually, in their case? It is not a practical application?

Dr. GMITTER. Not immediately practical.

Mr. VAN DREW. Is that true anywhere else? I mean, any other thoughts, please?

Ms. TENCER. I would just like to share that we hold an annual research forum to bring researchers from all over the country together with organic farmers to discuss both research findings as well as hear needs from the organic farming community, and the events are incredibly successful with farmers and researchers hungry for those opportunities.

Last year our forum was hosted by Rutgers University which is very satisfying for us. It is not an area that has always been proactive. They actually sought us out and said, "The farmers and researchers in this region want to do this, come together and share," and so I just want to say it was very successful.

We publish all those findings, but both the farmers and the researchers say they benefitted from those exchanges.

Dr. WOLFE. I would just like to add, I agree with what the others have said.

I still think though that our universities establish a certain approach to research that is very creative, and I don't think some of these other places like China have really gotten there yet.

Mr. VAN DREW. We are not getting blown away?

Dr. WOLFE. No, there is an issue where my graduate students by the time they are ready and their Ph.D. is just about done, they know more about their topic than I do and they are challenging me constantly about it.

That sort of challenge between faculty and students is not quite the same in China, I would say, and this really breeds a certain level of creativity. It is a subtle nuance maybe, but it is significant.

Mr. VAN DREW. Thank you.

The CHAIR. Thank you.

Mr. Dunn, if you have any closing remarks?

Mr. DUNN. I do not. Thank you.

The CHAIR. Okay. I want to thank our witnesses and all of my colleagues who were here this afternoon to be with us and this morning to participate in what has been for me extremely informative. We have really developed a record here with the kind of work and research that is going on, and it is efficacy and importance in resilience and mitigation and what can and should be done in this area for farmers and ranchers which are facing threats now, flooding, heat, drought, all of those things are faced by farmers, livestock owners, *et cetera,* throughout this country.

There is real value in investments for public agricultural research. Our farmers need more resources to better mitigate the risks that they face. They are our lifeblood and those that feed us and many people around the world, and we have to safeguard that resource.

This hearing underscored the importance of ensuring that farmers, ranchers, and researchers have a seat at the table in that discussion.

I want to thank you all for the information you have provided us, and let the record reflect that under the Rules of the Committee, the record of today's hearing will remain open for 10 calendar days to receive additional material, supplementary written responses from the witnesses to any questions posed by a Member.

This hearing of the Subcommittee on Biotechnology, Horticulture, and Research is adjourned.

[Whereupon, at 11:51 a.m., the Subcommittee was adjourned.]

[Material submitted for inclusion in the record follows:]

SUBMITTED FACT SHEET BY HON. CHELLIE PINGREE, A REPRESENTATIVE IN CONGRESS FROM MAINE

Organic trade association SINCE 1985

Organic Farming Practices Benefit the Environment

Organic agriculture is based on practices that not only protect environmental health, but also strive to improve it. By absorbing more carbon dioxide from the air and prohibiting the use of petroleum-based fertilizers, organic agriculture helps to reduce humans' carbon footprint, combat climate change, and protect the land and natural resources for future generations.

Organic Protects Natural Resources

Organic farming is a production system of cultural, biological, and mechanical practices that **foster cycling of resources, promote ecological balance, and conserve biodiversity.** Organic farmers are required to manage their operations in a manner that does not contribute to environmental contamination of crops, soil, or water. Production and management practices on organic farms must maintain or improve the natural resources of the farm, including soil, water, wetlands, woodlands, and wildlife.

Organic Prohibits Use of Toxic Synthetic Pesticides and Fertilizers

Instead of relying on synthetic pesticides and fertilizers that can deplete the soil of valuable nutrients and increase environmental degradation, organic farmers build soil and plant health using practices that incorporate organic materials like manure and compost. **Petroleum-based fertilizers are prohibited as are most synthetic pesticides.** Organic practices help keep our water supply clean of runoff from toxic and persistent chemicals.

Organic Promotes Soil Health and Reduces Erosion

Organic farmers use tillage and cultivation practices that maintain or improve soil conditions and minimize soil erosion. Using complex and diversified crop rotations, cover crops, green manure crops, and catch crops, **organic practices build soil health** and biodiversity, improve soil structure, and **increase nutrient availability without synthetic fertilizers.**

Policy Recommendations:

- ➢ Establish a commission to evaluate ecosystems services delivered by organic production, and recommend policies to reward and incentivize these ecosystem services.
- ➢ Develop a competitive grant program for providing technical services to organic and transitioning farmers.
- ➢ Provide market and infrastructure development grants for minor rotational crops that improve soil health.
- ➢ Provide tax credits for landowners who have long-term leases under organic production.

ORGANIC TRADE ASSOCIATION Bold Steps to PROMOTE and PROTECT ORGANIC | FOCUS ON SOLUTIONS | CONTINUOUS IMPROVEMENT | EMBRACE INNOVATION | PLAN FOR THE FUTURE

The Science Behind Organic and Soil Health

Organic standards require that farmers use practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion. Many research studies have found that organic practices improve a variety of soil health components.

Organic Farming Sequesters Carbon In The Soil

Many organic practices reduce greenhouse gas emissions and increase carbon sequestration in the soil. Organic farming increases soil properties that enhance long-term storage of carbon, providing a viable greenhouse gas mitigation strategy.[1]

Featured Study: The Organic Center co-authored a groundbreaking study with the National Soil Project at Northeastern University showing that organic soils combat climate change by locking away carbon, which would otherwise be in the atmosphere, in long-term reserves. The research compared over 1,000 soil samples from organic and agricultural soils as a whole to understand how organic compares to average agricultural management practices that influence components of soil organic carbon. The study was the first to compare the amount of total sequestered soil organic carbon—found in the form of long-lived humic substances—between agricultural systems on such a wide-scale basis. The findings showed that the components that make up humic substances were respectively 150% and 44% greater in organic soils. The results also show that soils from organic farms sequester 26% more carbon. Overall, these results demonstrate that organic farms store more carbon in the soil, and keep it out of the atmosphere for longer than other farming methods.[2]

Organic Farming Supports Soil Biodiversity

Since synthetic pesticides are prohibited, important organisms in the soil can thrive. Increased soil organic carbon found on organic farms provides important building blocks for beneficial microorganisms in the soil that are vital to decomposition and nutrient cycling.[3]

Organic Farming Increases Water Retention in the Soil

Organic management improves the ability of soil to store and retain water, which is critical for protecting crops against extreme weather events such as drought and flooding. It also protects water quality because less agricultural water is contaminated by runoff.[4]

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[1] Cooper J.M., *et al.* 2016. *Shallow non-inversion tillage in organic farming maintains crop yields and increases soil C stocks: a meta-analysis.* AGRONOMY FOR SUSTAINABLE DEVELOPMENT, 36, 1–20.

[2] Ghabbour E.A., *et al.* 2017. *Chapter One—National Comparison of the Total and Sequestered Organic Matter Contents of Conventional and Organic Farm Soils.* ADVANCES IN AGRONOMY, 146, 1–35.

[4] Moebius-Clune B.N., *et al.* 2016. *Comprehensive Assessment of Soil Health—The Cornell Framework Manual,* Edition 3.0. Cornell University: Geneva, NY.

[4] Lotter, D.W. 2003. *Organic Agriculture.* JOURNAL OF SUSTAINABLE AGRICULTURE, 21, 59–128.

SUBMITTED REPORTS BY HON. JIMMY PANETTA, A REPRESENTATIVE IN CONGRESS FROM CALIFORNIA

REPORT 1

2016 National Organic Research Agenda—Outcomes and Recommendations from the 2015 National Organic Farmer Survey and Listening Sessions

By Diana Jerkins and Joanna Ory
BRISE TENCER, *Project Director*
VICKI LOWELL, *Staff Contributor*

We thank the following reviewers for their invaluable feedback.

Heather Darby (University of Vermont)
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Contents

Executive Summary

This 2016 National Organic Research Agenda (NORA) report provides comprehensive recommendations for future investment in organic agricultural research. These recommendations are based on the Organic Farming Research Foundation's 2015 survey of organic farmers, nationwide listening sessions with organic farmers, and a review of key documents and recommendations from other organizations, including the National Organic Standards Board (NOSB). The 2015 Organic Farmer Survey was conducted online and completed by over 1,000 organic farmers. Their responses directly inform our top recommendations for organic research.

Top OFRF Recommendations

Based on feedback from survey respondents regarding high priority needs, OFRF recommends intensified research funding and attention to the areas of:

- Soil health and fertility management
- Weed management
- Nutritional benefits of organic food

- Insect management
- Disease management

OFRF also recommends prioritizing research in the following areas:

- Building the economic, environmental, and social sustainability of organic systems through more holistic studies, using functional agricultural biodiversity, permaculture, crop-livestock integration, and other advanced agroecological or agroecosystem research frameworks and methodologies.
- The impacts of genetically modified organisms (GMOs) on organic farms and strategies to avoid GMO contamination.
- The efficacy and environmental sustainability of approved products included on the USDA National List of Allowed and Prohibited Substances (organic insecticides, fungicides, and soil amendments).
- Livestock health, especially parasite control and organic animal nutrition.
- Development and selection of public livestock and poultry breeds for organic systems: performance in pastured systems, and parasite resistance.
- Social science research on the marketing, policy, and economic barriers to successful organic production and barriers to transition.
- Development of public crop cultivars bred and selected for organic systems: regional adaptation, nutrient efficiency, weed tolerance, and disease resistance.

This report details the research priority areas and includes a discussion of the survey results leading to the development of OFRF's recommendations.

Chapter One of this report discusses the research areas OFRF recommends for increased funding and prioritization. The first set of recommendations is directly informed by results from the 2015 National Organic Farmer Survey. The second set of recommendations refers to methodology and outreach activities related to organic farming research, and these recommendations are based on a broader review of recommendations from partner groups and the listening sessions that were held across the country. The chapter concludes with research priorities for each of the four U.S. regions.

Chapter Two provides detailed results from the 2015 National Organic Farmer Survey. These results include farmer demographics, stated research priorities, production challenges, and responses to open-ended questions. In addition, this chapter includes survey results on the special topics of climate change, food safety, and GMO impacts, and organic seed availability.

Chapter Three reviews several farmer surveys and reports that inform the OFRF recommendations. This chapter describes overlap between recommendations made by OFRF and other entities. This chapter also describes the research topics that were recommended for prioritization in the past, such as soil health and organic plant breeding, which remain areas in need of increased attention.

Joanna Ory.

The report concludes in the appendices section with four reports containing regionally specific results from the 2015 National Organic Farmer Survey and regional recommendations for organic research. The survey found that the topics of soil health and weed management were top priorities for all four regions. However, there was variability among regions for other top research priorities. For example, in the Southern region, there is a strong need for social science research to identify and provide strategies for overcoming barriers to market entry. In the Western region, a top priority is research on irrigation efficiency and coping with drought. For the North Central region, research on GMO impacts was among the top priorities. Pollinator health was a high priority for survey respondents in the North East region.

The recommendations and information in this 2016 NORA report will ensure research funding is relevant and responsive to the needs of today's organic farmers. In addition, we hope this research will be used to expand organic farming education at colleges, universities, and farms. We expect this report to help significantly increase funding for research that assists producers in adopting new practices that enhance the environmental sustainability and economic viability of organic operations.

Introduction

There have been significant advances in our knowledge of organic agriculture since OFRF's 2007 National Organic Research Agenda (NORA) (Sooby, *et al.,* 2007). This landmark document provided a clear and comprehensive blueprint for successful organic research systems, drawing upon the results of regional and topical working sessions of farmers, scientists, and agricultural professionals that took place over a period of 3 years to identify and prioritize research needs for organic agriculture.

The seed for the 2007 NORA report was planted almost a decade earlier when the OFRF report, "Looking for the 'O' Word," (Lipson, 1997) documented the virtual absence of Federal support for research relevant to organic agriculture. OFRF then worked to rectify this unacceptable omission by sponsoring unique collaborations between organic farmers and agricultural researchers to set organic research priorities.

The 2007 NORA report centered on four core topic areas: soil microbiology and fertility; system approaches to pest management; ruminant and poultry production systems; and crop and animal breeding and genetics. The report consolidated the results of existing research with practical experience from the field to validate the benefits of organic agriculture, especially with regard to yield potential, resource conservation, and biodiversity. Many of the recommendations from the 2007 report are still relevant today.

The 2007 NORA report firmly endorsed four principles that have become hallmarks of organic research:

- Work must occur on certified operations.
- Farmers must be actively engaged in experimental design and data analysis.
- Work should employ multidisciplinary system approaches rather than input substitution.
- Research must be maintained over an extended period of time.

Current Needs for Organic Research

Continued interest in organic research from the research community, combined with incremental increases in funding for organic research, inspired OFRF to provide a new, updated research agenda for organic agriculture.

The 2016 NORA report reviews areas of the original research agenda where significant progress has been made, and identifies areas where research needs have yet to be met. This analysis will help focus the next generation of research on the most relevant needs of farmers and ranchers.

Organic agricultural producers face unique challenges, from the availability of organic seeds, crop cultivars, and livestock breeds adapted to organic systems, to coping with weeds and pests, and using approved organic methods. As consumer demand for organic products soars, there is a growing need for solutions to organic farming challenges, training for future agriculture producers and leaders, and information on the benefits of organic agriculture.

Organic farming methods are knowledge-intensive and site-specific. Organic agriculture uses methods that protect the environment, avoiding the use of synthetic pesticides and fertilizers, antibiotics, and genetically engineered crops. Because organic farmers cannot use synthetic pesticides to control weeds and pests, they must rely on practices that holistically promote health of the agroecosystem and protect against pest infestations and soil degradation. Careful organic management includes:

- Selecting varieties suited for local soil, pest, and weather conditions.
- Managing the soil fertility specific to the past and present conditions of the land.
- Using rotations and crop diversity to protect against crop diseases and pests.

The needs of farmers in this quickly growing industry are continually evolving and include new concerns about food safety and regulation, invasive pests, environmental and social issues, changes in and expansion of national and international markets, changing weather patterns, and biological threats. These trends call for a fresh analysis of the needs of organic farmers and ranchers.

Domestic Demand

Domestic demand for organic products is growing rapidly. Although U.S. organic sales reached an all time high of $6.2B in 2015, there was also an increase in the importation of organic products in order to meet demand (USDA, 2016 a). To meet the growing U.S. demand for organic products in the long-term, domestic production of both crops and livestock and poultry products (especially milk and eggs) will need to increase. The majority of organic sales are concentrated in the top five organic-producing states: California, Washington, Pennsylvania, Oregon, and Wisconsin (USDA, 2016 a). These states have historically had strong links with land grant universities and non-government organization infrastructure supporting the growth of their organic industry.

Specific research, education, and extension programs are necessary to foster partnerships between producers and organic agriculture professionals; programs that integrate scientific knowledge with farmer expertise to develop practical and sustainable solutions.

In order to meet the growing demand for organic products domestically and internationally, research efforts need to provide solutions to production, risk management, marketing, and social issues confronting organic producers and distributors. In conjunction with these research efforts, there needs to be greater organic-specific extension activities to educate producers and consumers. By furthering research that directly meets the needs of the organic sector, we can enable U.S. producers to meet more of this demand. The 2016 NORA report helps chart the most efficient and effective course for USDA spending for organic agricultural research and for university and broader funding by State Departments of Agriculture, private foundations, and NGOs.

About OFRF

OFRF is sowing the seeds to transform agriculture by working for the continuous improvement and widespread adoption of organic farming systems. OFRF sponsors organic farming research and education projects and disseminates the results to organic farmers and growers interested in adopting organic production systems. The organization also informs the public and policymakers about organic farming issues.

OFRF is a leading grant maker for organic agriculture research and education, funding innovative research and education projects that lead to new production solutions for farmers and a stronger community among organic farmers. Since its founding, OFRF has funded 322 research projects with the aim of directly addressing the needs of organic farmers and ranchers. OFRF is one of the first nonprofit organizations to award grants dedicated to organic farming research, making important scientific contributions to organic knowledge and practice since 1990.

OFRF and its partners successfully lobbied for increased Federal funding for organic research in the Farm Security and Rural Investment Act of 2002 (aka 2002 Farm Bill), which resulted in the establishment of the Organic Agriculture Research and Extension Initiative (OREI) grant program authorizing $3M annually for 5 years specifically for organic farming research. Section 7408 of the 2002 Farm Bill directed research resources reflecting the growing interest in organic production and the need to provide enhanced research for the growing organic sector. This section of the 2002 Farm Bill created the Section 406 "Organic Transitions" competitive grants program.

In fiscal 2016, Congress approved the highest ever budget of $2.94B for USDA agricultural research. Within the USDA National Institute for Food and Agriculture (NIFA), funding for Agriculture and Food Research Initiative (AFRI) programs, the primary competitive grants programs within NIFA, has increased 20% over the last 5 years, and is slated in the 2017 Presidential budget for additional funding.

Only 0.1% of AFRI funding was used specifically for organic research between 2010–2014 (National Organic Coalition, 2016). Non-organic research within AFRI was $1.38B, while spending on organic research was $1.48M.

Joanna Ory.

Goals of the 2016 NORA Report

The 2016 NORA report presents a catalogue of research needs for organic agriculture based on feedback OFRF obtained through an extensive survey and listening sessions with organic farmers. This survey was an opportunity to make organic farmers' and ranchers' voices heard. In an ongoing effort to reach out to the organic community, OFRF wanted to learn about challenges and research priorities directly from producers. The feedback received identified the obstacles today's farmers face and the information they need most to be resilient, grow, and thrive.

As with any agricultural endeavor, scientific research needs can be applicable to all farmers and ranchers and/or specific to location, soil type, crop, and livestock produced, and the agricultural knowledge level of the farmers and ranchers. As seen in previous surveys and reports, the specificity of research needs is almost unlimited in the sense that each farmer or rancher has unique needs and requirements to meet the demands of their individual enterprise

This research agenda looks at both the general research needs and specific challenges identified by multiple stakeholder groups. The recommendations cover six topical areas from national and regional perspectives, as well as the most appropriate approaches to conducting organic research. The report also includes continuing priorities and specific research topics that were identified in previous surveys and reports. It also includes recommendations to address basic and applied research needs, as well as organic agriculture education and extension activities to promote optimum delivery and use of research outcomes.

Vicki Lowell.

The 2016 NORA report will inform USDA researchers, universities, agricultural extension agents, farmers, ranchers, and others on how research, education, and extension activities can be focused to meet the needs of organic farmers and ranchers to support organic agriculture and increase organic acreage. The report provides key information for how OFRF and other funding entities can continue to inform grant making to most effectively support the success of organic farmers and ranchers.

1. National Research Recommendations

U.S. Wide Priorities for Research, Education and Extension

OFRF's 2015 National Organic Farmer Survey, auxiliary stakeholder input, and supplemental reviews provide a basis for making recommendations for future research to support the production, marketing, environmental, and societal needs of current organic farmers, ranchers, and those entering organic agriculture. Farmers were asked to rate research topics based on their priority. The five areas rated highest in priority by the 2015 respondents are displayed in *Table 1.*

Table 1. Priority ratings for research topics from the 2015 OFRF National Organic Farmer Survey.

Research Topic	Percentage of survey participants who rated as a **high** priority
Soil health, quality, and nutrient management	74%
Weed management	67%
Fertility and nutrient management	66%
Nutritional quality, health benefits, and integrity of organic food	55%
Insect management	51%

Based on these top priorities, OFRF recommends increased research in the following areas.

- **Soil health as the basis of organic agricultural productivity, specifically:**
  - Defining soil health criteria.
  - Researching soil health and best practices for coping with climatic variability.

  - Developing tools for rapid measurement of soil health/quality.
  - Investigating the relationship between soil quality and crop management practices, such as cover cropping, crop rotation and diversification, crop-livestock integration, and reduced tillage.
  - Researching the efficacy of different soil amendments for building soil fertility and enhancing yield.
- **Organic weed control, specifically:**
  - Researching how weed infestations are impacted or enhanced by soil management, crop rotation, cover crops, crop-livestock integration, and inputs.
  - Researching the most economical ways to manage weeds in organic systems.
  - Evaluating weed management strategies that integrate soil improving practices (cover crops, rotation, reduced tillage) with NOP-allowed control tactics.
- **Organic fertility methods and practices, specifically:**
  - Researching agroecological approaches to organic farming and moving beyond input substitution.
  - Determining appropriate levels of fertility inputs to match crop needs throughout the season and minimize nutrient losses.
  - Researching how organic farming can integrate agricultural methods from biodynamic and permaculture practices to decrease environmental impacts.
  - Evaluating, breeding, and selecting crop cultivars for greater nutrient use efficiency and ability to thrive on low-solubility organic nutrient sources.
  - The relationship between nutrient balancing fertilization practices and microbial life in the soil and susceptibility or resistance to pests.
- **The whole farm ecosystem, specifically:**
  - The impact of habitat diversity and cropping systems on biological diversity on the farm as well as yield stability and pest and disease resistance.
  - The ecosystem services provided by diverse agroecological systems.
  - How food safety practices can coexist with practices that protect wildlife.
  - The environmental and agricultural effects of homogeneity in conventional production management, *i.e.,* only using GMO seeds, only chemical sprays, *etc.*
  - The environmental benefits of organic farming for water, soil, climate, biodiversity (including pollinators), wildlife, native plants, soil microbes, and agro-biodiversity.
- **Nutritional quality, health benefits, and integrity of organic food, specifically:**
  - Researching how organic and conventional foods differ in terms of nutrients, pesticide residues, and impacts on consumer health.
  - Researching how to best educate and inform consumers about the benefits of organic food.
  - Comparing the nutritional value of organic *versus* conventional food.
  - Examining the best ways to attract new organic consumers and increase consumer demand for organic products.
- **Organic insect pest control, specifically:**
  - The control of new, invasive insect pests.
  - The efficacy of organic pest control products, especially the Organic Materials Review Institute (OMRI) approved products.
  - Integrated pest management strategies.

In addition to the 2015 National Organic Farmer Survey results, OFRF conducted listening sessions with organic farmers and researchers to further understand how research can meet the challenges of organic farmers. Based on these listening sessions and review of the recommendations presented by the National Organic Standards Board (NOSB), OFRF offers additional recommendations aimed to increase the environmental, economic, and social sustainability of organic farming and ranching in the U.S. These recommendations include:

- **Increase research on specific systems within organic agriculture to understand best management practices.**

- ◦ Researching the applicability and benefits of techniques used in aquaponics, biodynamic production, and permaculture to enhance organic production.
- ◦ Researching different tillage systems such as low or no tillage systems for organic systems.
- ◦ Measuring the benefits of ecosystem services and how organic producers can enhance these services for their economic benefit.
- ◦ Increasing research on row crops to raise the percentage of agriculture adopting organic methods to produce row crops.

- **Increase research investment in grain and seed production, specifically:**
  - ◦ Economic and agronomic research to increase organic grain production. Grain production in the U.S. does not meet the demand for the organic food, seed, and feed industry (USDA, 2013). A difficulty for farmers is a lack of scientific knowledge and training on how to change from traditional continuous grain production to more complex rotational patterns needed for organic production.
  - ◦ Researching rotational patterns that take into account plant nutritional needs, water resources, soil quality, weed and disease control mechanisms, and the variety of crops to be grown for soil building and economic needs.
- **Increase investment in animal production research, specifically:**
  - ◦ Researching organic production of minor species such as sheep, pigs, and bees.
  - ◦ Past research funding by OFRF and OREI has focused on crop production instead of animal production. For example, OREI funding was allotted 71% to crops, 10% to livestock and poultry, and 19% to general topics covering both crops and animals, including crop-livestock integrated systems. OFRF recommends that a greater portion of research funds be allotted for animal production research.
- **Increase research on climate change and associated environmental and agronomic impacts, specifically:**
  - ◦ Researching precipitation variability and the impacts and innovations for drought and flooding.
  - ◦ Researching climate change adaptation strategies for organic farmers.
- **Increase breeding crop varieties specific to organic production, specifically:**
  - ◦ Crop breeding to enhance performance in sustainable organic production systems.
  - ◦ Crop breeding to improve market quality and nutritional content.
  - ◦ Crop breeding to increase resilience to stresses like disease and weed pressure.
- **Increase research on economic and social issues, including:**

> **Minority and women farmers are making up a greater percentage of the agricultural workforce and may have specific needs** (USDA, 2014).

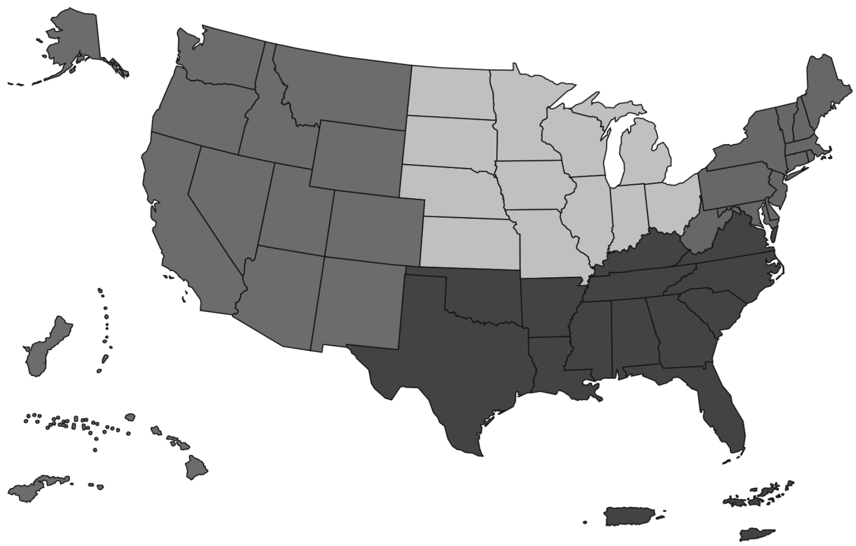
  - ◦ Economic and social barriers to adopting organic farming practices.
  - ◦ How to decrease barriers to entrance into organic agricultural production.
  - ◦ The unique technical assistance and programmatic needs of minority producers and women farmers and ranchers. Minority and women farmers are making up a greater percentage of the agricultural workforce and may have specific needs (USDA, 2014).
  - ◦ How to balance economic and environmental outcomes in a multifunctional agricultural production system.
  - ◦ The retention of current producers, access of new and transitioning farmers, and how to entice new farmers/ranchers, *i.e.,* access to land and financing, economic support, training, and long-term mentoring.
  - ◦ Ways to decrease the loss of agricultural lands in rural areas and nurture the revitalization of urban agriculture.

- ◦ How to improve and meet market demand for organic agriculture products nationally and internationally.
- ◦ The link between crop insurance and organic production and conservation practices.
- ◦ Researching the marketing needs of future farmers including market access and structure, land access, and rural economics.

Regional Recommendations

The National Organic Farmer Survey results were analyzed by region to take into account specific geographic needs, cropping/animal species, and environmental issues. In general, the regional research priorities reflect the overall national trends, with some variations based on regional concerns. Based on the survey results, OFRF recommends the following research prioritization by region (*Figure 1*).

Figure 1.



Regions listed by color. Blue = Western, Yellow = North Central, Green = Northeast, and Red = Southern.
Source: SARE.

Western Region

- Provide beginning and transitioning farmers and ranchers the tools, knowledge, and on-going mentoring to be successful organic producers.
- Prioritize research on water management in drought conditions, water efficiency technologies, and innovations for water deficit management.
- Continue long-term research on soil health with focus on nutrient and water management.
- Prioritize research on organic production practices that can increase carbon sequestration and mechanisms for producers to capture economic benefits from that ecosystem service. Current research shows that organic soils with higher soil organic matter can increase the sequestration of carbon in the soils. Organic practices such as cover cropping and incorporating residues into the soil build organic matter and sequester carbon.
- Prioritize research on weed control. Research can increase the effectiveness of weed control practices, especially for decreasing the pressure from invasive weeds. Efficacy of organic weed management practices and products will also benefit farmers as they select efficient and cost-effective products. Different tillage regimes and plant and animal rotations are of special interest to the relationship between soil quality and weed control.
- Invest in research to find solutions for disease and pest problems of high regional importance. In addition to general research on specific insect controls, continued efforts in breeding plants specific to organic production challenges, will increase the productivity and economic viability of organic producers.
- Increased research and extension efforts need to be provided for all aspects of animal production, especially information on best practices for rotational and grass fed animals. The Western region is a major producer of milk products and organic livestock and poultry, and research should prioritize animal health in relationship to environmental health as well as follow the integrative OneHealth approach to attain optimal health for humans, animals and the environment. In addition, forage and pasture management is an important focal area for research.

North Central Region

- Increase research on soil health, especially soil fertility under different tillage regimes.

- Increase research related to livestock production and management.
- Increase research on the environmental and economic impacts of genetically modified organisms (GMOs) on organic farmers, as well as strategies for GMO avoidance.
- Increase research on any verifiable health benefits of organic food, and how this can be used to enhance labeling and broader marketing strategies.

Southern Region

- Increase research on marketing strategies and profitability of southern organic operations.
- Increase research and technical outreach on maintaining soil health through organic methods like cover cops, crop rotations, and soil amendments.
- Increase research on weeds and insect management, especially pests of increasing concern like squash bug.
- Increase research on climate adaptive agricultural practices for coping with the higher prevalence of extreme weather patterns like excessive rain and flooding.

Northeast Region

- Increase research on different tillage techniques and the impact on soil health and weed control.
- Increase research on the soil health and fertility impacts of integrating animal production within field crop systems.
- Increase research on cover crops (different varieties) for erosion control and fertility management.
- Increase research on the nutritional benefits of organic production practices and the resulting foods produced.
- Increase research on pollinator health and providing native pollinator habitat.
- Increase research on managing weeds, disease, and animal health challenges during wet years.

Recommendations for Organic Research Methods and Outreach Strategies

Research for organic systems must reflect the foundational principles of sustainable organic production, and be compatible with restrictions of practices or products used in organic production and processing.

Specifically, organic research should:

- Be conducted under certified organic conditions.
- Involve organic producers as active team members.
  - ○ Organic farmers should be trained to write research proposals and conduct research, maintain records of data, and maintain areas where trials have been established. They should be engaged in project goal setting and planning as well as execution, outreach, and evaluation.
  - ○ Advisory boards that include producers, and compensate them for their time and expertise, should be a priority for funding research.
- Expand the work in farmer participatory plant breeding and animal breeding, and evaluation of cultivars and livestock and poultry breeds for organic systems. Organic and sustainable farmers need access to plant and animal germplasm suited to their regions and management systems, and resilient to climate change.
- Emphasize multidisciplinary and agroecological systems approaches, rather than input-substitution approaches.
- Have capacity for long-term studies of organic systems.
- Include compliance with the National Organic Program (NOP) rules and the principles of sustainable agriculture as criterion for proposal review and field management during the study.
  - ○ Include research on medium- and large-scale production systems. Research questions should also include the techniques needed for scaling up or the adoption of larger scale organic agriculture, *i.e.,* production techniques, technologies, transition methodologies, and marketing strategies.
- Ensure information is delivered in appropriate forms to appropriate audiences.

Education and extension programs intended to deliver research outcomes to organic farmers and ranchers must be tailored to the unique needs and learning styles of the organic farming sector. Producers must be engaged as equal partners with scientists, service providers (Extension, other agencies, independent consultants), and other stakeholders in the process of acquiring and applying science-based information. Specifically, education and extension efforts should:

- Enhance and encourage producer adoption of research results by engaging producers in all phases of research and outreach, and by presenting scientific outcomes as complementary to farmer experience, skills, perspectives, and on-the-ground knowledge of their farming systems, integrating education and extension with research efforts.
- Identify the most effective approaches to facilitate adoption of organic production and marketing research results.
- Identify appropriate venues to successfully reach growers, crop consultants, agency personnel (Natural Resources Conservation Service, Risk Management Agency, Farm Service Agency, *etc.*), commodity organizations, state organic organizations, the extension system, and consumers.
    - Organic research funders should provide dedicated funding through scholarships and fellowships for undergraduate and graduate students choosing to work in fields related to agriculture and specifically organic agriculture to support future teaching and technical careers. Attention should be given to the special need for more plant and animal breeders and soil scientists.

Liz Birnbaum.

2. OFRF 2015 National Organic Farmer Survey

The 2015 National Organic Farmer Survey describes new and continuing research needs that farmers and ranchers have expressed since the last NORA report. OFRF believes this information will provide a basis to guide researchers, extension personnel, and educators in identifying future work that will be most relevant to producers. This information is especially needed for new and transitioning organic farmers and ranchers. In order to meet the goal of significantly increasing participating organic producers and acreage into organic production, relevant research information is required. Justification for the need and relevance of research on organic agriculture has been well documented. Therefore, the goal of this report is to identify the next generation of research activities.

Methods

A mixed methods approach was adopted to better understand the research needs of certified organic farmers in the U.S. A national survey, developed by OFRF and administered by Washington State University, was used to solicit feedback. The survey data was augmented by 21 listening sessions held around the country, in conjunction with regional organic farming meetings.

Researchers, farmers, and other organic organizations vetted the survey to determine the most appropriate questions to understand the current needs of organic farmers and ranchers, and their responses were consolidated into the survey document. OFRF conducted the survey from July to September 2015. It was sent electronically to six,631 certified organic producers who provided email addresses on the USDA National Organic Program certified producers list. OFRF mailed postcards to farmers who did not provide emails to inform them of the survey opportunity. In addition, organic certifiers contacted farmers on OFRF's behalf to encourage them to participate in the survey. However, because the survey was web-based, there may be a bias that farmers with computers and Internet were much more likely to participate in the survey than those without.

The survey received a response rate of 1,403 organic farmers, which represents approximately 10% of the current population of U.S. organic farmers (USDA, 2015). Survey responses came from every state, yet there was a predominance of responses from the Western (45%) and North Central (28%) regions, as defined under the USDA Sustainable Agriculture Research and Education (SARE) program.

Concurrent with the development of the survey document, OFRF worked in partnership with regional farming associations to gather additional input through 21 listening sessions around the country. Attendees were asked about general research topics and participated in small breakout groups related to specific topics. For example, at the MOSES conference, the listening sessions covered the topics of animal production, plant health, and soil health.

Farmer Demographics

Survey participants included organic farmers throughout the U.S. The Western region had the highest participation (555 farmers), followed by the North Central region (341), the Northeast region (204), and the Southern region (139). According to the 2014 USDA NASS organic survey, the number of organic farmers are: Western region (5,029); North Central region (4,309), Northeast region (3,371), and Southern region (1,294). Thus, about 11% of Western and Southern region farmers participated in the survey, while participation was closer to 7–8% in the Northeast and North Central regions.

- Farmers ranged from 20 to 84 years in age, with the average of 55 years of age. The median age was in the 60–65 age bracket.
- 70% of respondents identifying as the primary farmer or rancher were male and 30% were female.
- Farmers ranged in their organic farming experience from less than 1 year to 80 years, with the average being 13 years.
- Most farmers had between 5–10 years of organic farming experience, indicating that many survey respondents were either beginning farmers or had recently transitioned to organic production.
- The size of organic farms ranged from less than an acre to 40,000 acres. The median organic farm size was 48 acres.
- 98% of surveyed respondents had certified organic acres, 24% also had conventional acres, 18% had acres transitioning to organic, 16% had organic but uncertified acres, 7% had organic acres exempt from certification, and several farmers used biodynamic methods.
- The farmers in the survey were evenly divided among those who transitioned to organic agriculture from conventional farming (46%) and those who began farming using organic practices (48%). Several other farmers began farming in other ways, such as transitioning part of their land or starting to farm on conservation acreage.
- 38% of farmers earned 75–100% of their net income from organic farm production, yet the majority of farmers also received much of their income from off farm activities.
- 46% of respondents reported that a family member works off-farm for more than 20 hours a week.
- 25% of respondents stated that neither they nor their employees have access to health insurance practices, and 48% began farming using organic practices.

- 6% percent of farmers entered into organic farming either by taking over an existing organic farm, starting a split organic/conventional farm, or farming land from the Conservation Reserve Program (CRP).
- Surveyed farmers grew a wide variety of crops, with the most common being vegetable crops (55%). Forty-one percent (41%) of farmers produced animal products, with the most commonly produced animal product being beef. Twenty-eight percent (28%) of respondents also produced value added products.

Educational Background

Twenty-five percent of respondents received a masters or higher degree, 38% received a 4 year (bachelor) college degree, 8% received a 2 year college degree, 17% had 1 or more years of college but did not receive a degree, and 11% had high school education or less.

On-farm Research

Most surveyed farmers (66%) reported that they are experimenting or trying new production techniques on their farm. On-farm experimentation included the use of different cover crops, trying different tillage practices, performing variety trials, growing new crops, using different kinds of mulch, using different rotational design, monitoring and experimenting with irrigation practices, and breeding animals. One farmer expressed their experience as, "Almost every act is an experiment in improvement. Every year I try something new."

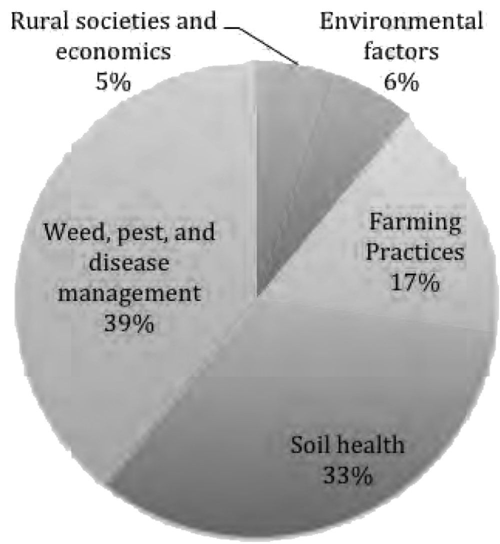
Marketing Venues

Surveyed farmers sold their products in many different venues. The most common marketing strategy was selling wholesale to processors or packers. The second most common marketing strategy was selling to a local food store or co-op. Direct to consumer marketing was commonly achieved through "U Pick," farmers' markets, and community supported agriculture (CSA). Only 21% of surveyed farmers used their websites for direct-to-consumer sales

Selected Research Priorities

When survey participants were asked to designate their highest priority overall for organic farming research, the most common topic was weed, pest, and disease management. The second most common top priority was soil health, followed by farming practices, environmental factors, and rural societies and economics (*Figure 2*). Weed, pest, and disease management as the highest priority matches the results of the 2011 National Organic Farmer Survey. Soil health, which ranked as a moderate challenge in 2011, has increased as a current priority. This may be due to a better understanding of the importance of healthy soil as the basis of organic production, and the ability to better cope with environmental and nutritional impacts.

Figure 2.



Prioritization of research topics by surveyed organic farmers (N = 1,039).

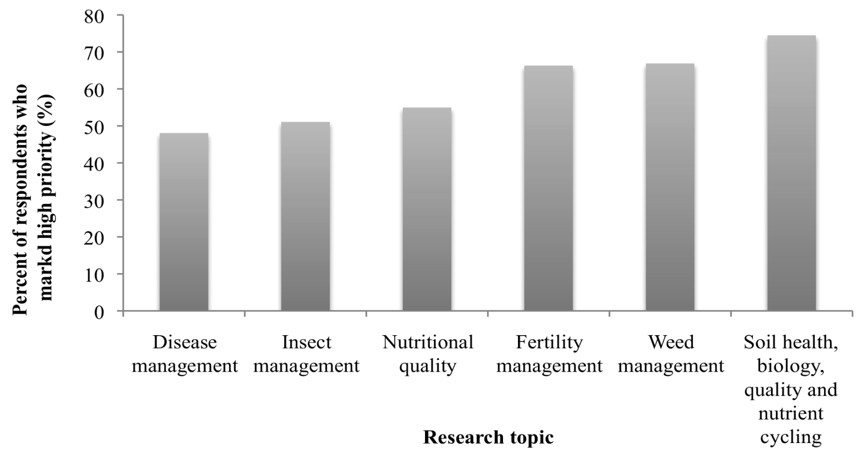
Top Rated Research Topics U.S. Wide

Producers surveyed were asked to rate specific research topics individually as high priority, moderatepriority, low priority, or not applicable. Each topic was ranked independently, and surveyed farmerswere able to mark multiple topics as high priority. *Figure 3.* shows the topics most often rated as highpriority research topics by survey participants. The five research areas that received the greatest percentof high priority ratings are:

1. Soil health, biology, quality, and nutrient management
2. Weed management
3. Fertility management
4. Nutritional quality, health benefits, and integrity of organic food
5. Insect management

We selected these top five priorities for further discussion in the following section of this chapter.

Figure 3.



Topics rated as high priority research topics U.S. wide.

Soil Health, Biology, Quality and Nutrient Cycling

Federal organic standards require producers to maintain or improve soil organic matter content. Practices such as cover cropping, reduced tillage, compost application, and rotational grazing are standard organic farming practices. The research topic of soil health, biology, quality, and nutrient cycling was consistently rated as a high priority in all regions, and overall was rated a high priority by 75% of respondents.

Specific needs in this research area focused on the interactions between soil health and the need for holistic soil research that examines the farming challenges of weeds, soil disease, maintaining a diversity of soil microbial life, climate stresses, and the economics of maintaining fertility. One farmer stated, "I would like to know more ways to increase healthy mycorrhizal interactions and other microbial activity, as well as improve the health for our plants without importing a ton of stuff."

Top issues related to soil health for which respondents requested research include:

- The connection between different tillage practices and the loss of soil carbon.
- The effects of cover crops, compost, and diverse rotations on fertility rates.
- Strategies for building soil organic matter.
- The needs of soil microbes and their role in crop health and disease and weed suppression.
- Insect and disease management interactions with soil biology, including the control of nematodes.
- The best ways to source effective and affordable soil amendments.

The 2007 NORA report had several recommendations for applied soil health research. Many of these recommendations have been addressed in research funded by the USDA OREI program. Sixty-five percent (122) of projects funded by OREI from 2002–2014 studied a topic related to soil management in organic production systems, with most projects focusing on soil fertility and nutrient management. These projects have produced important contributions to the knowledge surrounding organic soil health.

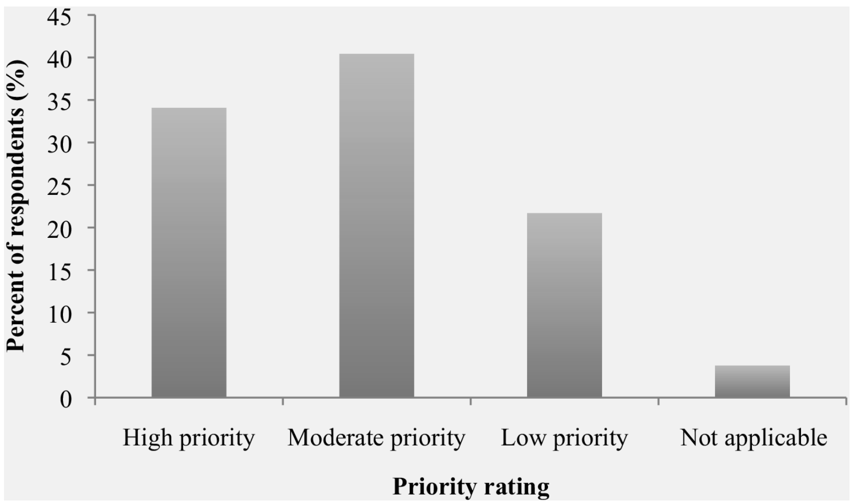
At least 36 OREI and ORG funded projects tackled the weed management/soil health dilemma with integrated approaches emphasizing cover crops, diversified crop rotations, and reduced tillage. Many of these projects also addressed nutrient management, crop pests, and diseases. In addition to field assessments of soil quality, weeds, and crop yields, many project teams analyzed soil microbiological communities or weed seed banks, and soil carbon sequestration. An example of a holistic project with a focus on soil health is: *Cropping intensity and organic amendments in transitioning farming systems: effects on soil fertility, weeds, diseases, and insects* (ORG 2003–04618, PI: Eastman, University of Illinois, $483,000).

Most organic crop growers operate on the premise that high quality soils are healthy soils, which yield healthy plants that are better able to resist insect and disease pests and produce high-quality food. Research on the relationships between above- and below-ground biodiversity, soil quality, plant health, systemic pest resistance, and crop quality need to be prioritized for future funding.

Climate Change

The survey respondents were asked about research needed on climate change. Specifically, respondents were asked to prioritize research on adaptation and mitigation for fluctuations in temperature and rainfall. Thirty-four percent of respondents nationwide marked this topic as a high priority for research (*Figure 4*). The Southern region stood out with 42% of respondents having marked climate fluctuations as a high priority for research.

Figure 4.



Priority rating for research on adaptation and mitigation to temperature and rainfall fluctuations (N = 1,104).

Recommendations

It is recommended that future research focus on the following topics of importance to organic farmers:

- Water and soil management to cope with drought and flooding (in crop and pasture systems).
- Coping with new insect and weed species.
- Ways to manage fluctuations in chill-time for nuts and fruits crops.
- Education and outreach on organic farming climate change adaptation and mitigation.

Survey Participant Comments

Specific comments given in the survey related to climate change reveal that organic farmers are experiencing negative impacts from climatic shifts. Impacts reported by farmers include new challenges with irrigation, weeds, energy costs, chill time for tree crops, and the difficulty of dealing with variability in the production system. Farmer quotations related to research needs and challenges of climate change include:

- *Irrigation is not truly sustainable, and especially with challenges due to climate change we need better practices that improve our water capture, retention, and cycling (rather than relying upon irrigation that too often utilizes below ground water faster than those reserves can be replenished). It is clear that much of the farming (even certified organic) being practiced in arid parts of the U.S. and abroad is not sustainable. We need to retain sustainable agriculture in more temperate areas (subject to development and land use conversion pressure) before that land is lost forever to farming. Research is needed to "validate" and further the alternative practices that are working.*

- *How can I cope with effects of climate change and increased energy costs?*
- *We need better ways to manage weeds and new insects. How to cope with them? Old diseases showing up more often due to climate change.*
- *Climate change is about to put me out of business. 2011 was too wet, 2012 too dry, 2013 and 2014 too wet and 2015 on track to be too wet. Plus devastating extreme cold temps in Jan 2014 and Feb 2105. How can I, as the manager, and the beef cattle deal with it?*
- *Two perennial crops particularly important to our farm income are (1) berries; (2) dry hay. In climate change, it will be very important for us to know what varieties of berries and varieties of dry forage we should eliminate and what varieties we should add.*
- *Climate change, radical fluctuations of temperatures and rainfall.*
- *Climate change adaptive techniques and crop breeds.*
- *Climate change, and specifically chilling hours, is negatively affecting our walnut orchards. Research into this field is very important to us.*
- *The role of grazing livestock to reverse climate change.*
- *Anticipating the changes on the horizon—increased energy costs, climate change, depleting natural resources—and how to adapt.*
- *Weather fluctuation from climate changes. Hot to cool or overly wet to bone dry conditions.*
- *Impact of climate change (weather extremes) on vegetable production.*
- *Climate change has drastically affected our pistachio production due to insufficient chilling hours. We need trials and research to help this growing industry survive these new challenges.*
- *Impact of climate change and unpredictability. Flexibility to adapt to unexpected and extreme conditions.*
- *Climate change disrupting fruit set and maturity dates.*
- *Climate change with water issues.*
- *Weeds and climate change.*
- *Sadly, I think climate change is going to catch up with all of us: it is getting hard to produce crops that have been routine to me over the decades.*

Weed Management

Weed management was rated a high priority for research by 67% of respondents. One farmer stated, "Weeds are killing me. I need better ways to control them in row crop production." Another farmer noticed cyclical patterns in the weed pressure on their farm, stating, "Weed pressures on our farm seem to change over time. When we were conventional, we had a lot of velvetleaf. While we can still find it since we have gone organic 16 years ago, it is not a problem for us at all. However, in recent years, we have some fields with a terrible bindweed infestation that we struggle with, and last year jimsonweed went from something we were hardly aware of to a big problem. More information on weed control would be valuable to us."

Respondents stated the need for research on several weed related topics, including:

- Cost effective methods for controlling weeds in medium/small scale operations (including organic herbicides).
- The role of cover crops in improving weed control.
- The role of crop rotations in improving weed control.
- Specific weed species: jimsonweed (*Datura stramonium*), Canada thistle (*Cirsium arvense*), field bindweed (*Convolvulus arvensis*), pigweed (*Amaranthaceae amaranthus* spp.), lambsquarters (*Chenopodium album*), and problematic perennial weeds.
- *Weeds and What They Tell* by E. Pfeiffer needs to be updated and expanded.
- Weed pests, insect problems, and diseases can be symptoms of wrong cultural practices and we need to learn to read the symptoms and know how to address the core problems.

Recommendations for research on weed management from the 2007 NORA report are still relevant, especially the need for models of weed population dynamics under different cover crop, tillage, and crop rotation management strategies. In addition, bindweed, pigweed, nutsedge, lambsquarters, and Canada thistle were all identified in the 2007 NORA report as difficult-to-control weeds. These weeds continue to be problematic and were identified in the 2015 National Organic Farmer Survey as top weed pests.

Fertility Management

Fertility management was rated the third highest priority, with 66% of respondents rating it a high priority. This research category is closely linked with the soil health category, yet it is more specific to the soil fertility challenges experienced by many organic growers. Growers' comments expressed particular research needs on soil fertility including:

- The correlation between soil biology adjustments (compost tea and other products to stimulate soil biology) and yield and fertility.
- The connection between soil fertility and weed pressure.
- How cover crops can be used to provide fertility requirements in perennial systems where tillage is not used.
- The types of compost that work best to maintain fertility and improve biological processes. Research on varieties that require less fertility inputs and compete better with weeds.
- The preparation of soil for pasture management, including timing and technique for amendment application and incorporation and grazing. What does the 5 to 10 year pasture management plan look like?

Nutritional Quality, Health Benefits, and Integrity of Organic Food

OFRF recommends increased research on nutritional quality and the integrity of organic food. Organic marketing faces the challenge of many different food labels, like natural and non-GMO, which may lead to consumer confusion about the organic label. Fifty-five percent (55%) of growers rated nutritional quality, health benefits, and integrity of organic food as a high priority. Increased research in this area is important for aiding organic farmers with marketing tools. Key issues for research include:

- The quality, health benefits, and organic integrity of organic food and body care products.
- Consumer education regarding the irregularities in appearance of organic produce, the health benefits of organic food, and the environmental benefits of organic farming.

Joanna Ory.

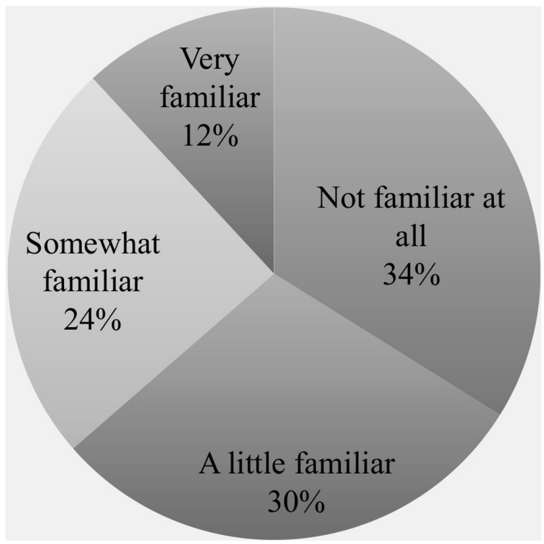
- Research that shows the nutritional and other benefits (environmental and consumer) of mindfully, truly sustainably grown organic products (*e.g.,* 100% grass-fed organic dairy products *vs.* confinement organic dairy).
- Research to educate the younger generation on the benefits of organic nutrition and farm practices.
- Economic structure and integrity of labeling and marketing messages of organic milk products.
- The organic integrity of imported organic grain, including the environmental and social impacts of production. Farmer quote: "The rising tide of industrial scale organic grain and livestock production threatens the integrity of organic food and the social and environmental benefits that come with ecologically based, diversified organic crop/livestock production systems."
- The organic label needs to integrate good labor practices and reduced energy use.

Food Safety

In 2011, the U.S. Food and Drug Administration (USDA) created a new law, the Food Safety Modernization Act (FSMA). This act directed the Food and Drug Administration (FDA) to establish a set of preventative controls across the food system in order to minimize the occurrence of food-borne illness. These controls include requirements that food facilities develop a food safety plan that includes hazard analysis, prevention controls such as a food allergen controls and recall plans, monitoring, corrective actions, and verification such as product testing. Farms are required to have produce safety standards for the safe production and harvesting of fruits and vegetables, considering potential sources of pathogens, the use of soil amendments, hygiene, packaging, temperature, and the presence of animals in crop production areas. These on-farm requirements have the potential to affect organic farms. For example, compost must be stabilized in order to limit the amount of bacteria like *Salmonella* spp. FSMA also encourages waiting periods between grazing and harvest. The rule exempts small farms (sales less than $500,000/year), which sell directly to local consumers.

In the 2015 National Organic Farmer Survey, OFRF asked organic farmers to rate their familiarity with the FSMA rules. Most respondents (64%) reported little or no familiarity with the rules, and only 12% stated they were very familiar (*Figure 5*).

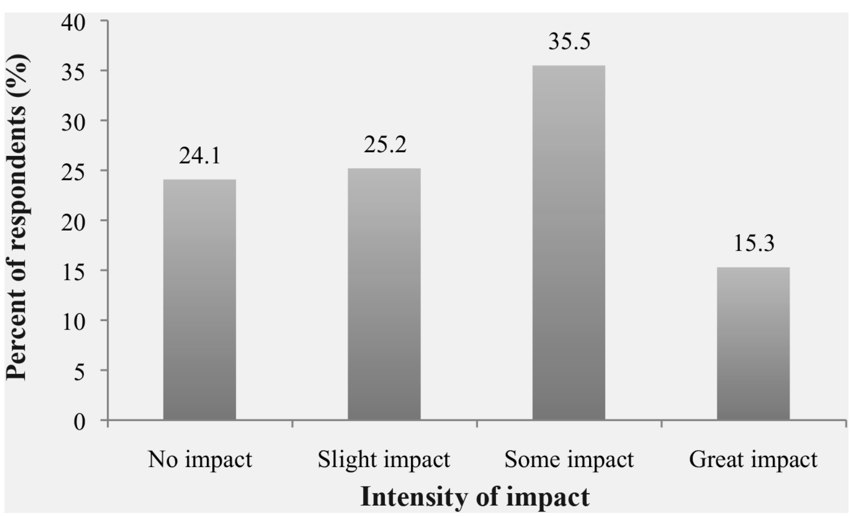
Figure 5.



Familiarity of respondents to FSMA.

Further, farmers were asked to rate and describe any possible impacts they feel FSMA may have on their operations. Most farms stated that FSMA would have a slight or moderate impact on their operations (*Figure 6*).

Figure 6.



Respondent predicted impact severity of FSMA.

When asked what the specific impacts may be, many farmers stated that they are uncertain. The most common impact reported is the burden of record keeping and paperwork. However, some farmers stated more significant impacts like changing their growing practices. One farmer stated, "We have been USDA certified (food safety) now for 3 years and have had to fight to maintain our livestock on the farm each year. We have decided to quit growing leafy greens and other crops that keep hitting the news with food scares. We have been able to maintain our tree crops as food safety certified because these crops do not come into contact with the ground. The food safety regulations are totally against integrated crop-livestock operations, which have so much potential to stabilize farm income and provide a great agronomic program as well. The cost of the inspections is very high, and the effort we go through to pass inspections is very taxing. I'm certainly not against food safety, but there needs to be more research to demonstrate the real causes of food poisoning: it's the processing, handling and packaging on an industrial scale."

Other farmers mentioned no longer growing crops that will be eaten raw. Still others were concerned that the costs of inspections and compliance could "force them out of business." One respondent stated, "We are facing the possibility of losing my ability to do simple on-farm processing (sun-drying) of my products, because of ill-guided 'food safety' new regulations."

Many farmers feel that the rule will have minor impacts because they already have certain rules in place to meet organic certification. For example, the rule for the waiting time between raw manure application and harvest will most likely be equivalent to the National Organic Program standards. Therefore, many organic farmers are already in compliance with at least some of the new food safety rules. One farmer stated that there is a benefit of the new rule, "I think it can help make our farm more aware of food safety issues on the farm and therefore will likely motivate us to pay closer attention to this often overlooked area."

Research on Food Safety

Research on food safety issues was rated a high priority by 36% of respondents. Farmers stated they were interested in several research areas related to food safety, including:

- Quantifying food safety risk, or lack thereof, in providing on-farm habitat in the form of hedgerows and buffer strips.
- Evaluating post-harvest handling with regard to food safety.
- Evaluating the wait time before harvest for food safety.
- Minimizing food safety risks on small farms—beyond just getting GAP certified.
- Researching food safety risks of animal manure (either left there by grazing rotations or applied).

Insect Management

Insect management was rated a high priority by 51% of respondents. Farmers noted specific insect pests for which they would like new research and treatment options, as well as more general topics such as insect conservation and research on habitats for beneficial insects, like syrphid flies. The most frequently reported problematic insect pests are aphids, flea beetles such as *Phyllotreta cruciferae,* ants, Bagrada bug (*Bagrada hilaris*), and cucumber beetles (*Aclymma vittatum, A. trivittatum,* and *Diabrotica undecimpunctata*). Since the publication of the 2007 NORA, there have been several invasive insect pests that have been introduced to the U.S. or increased their range. These new invasive pests include:

- Chilli thrips (*Scirtothrips dorsalis* Hood) was discovered in Florida in 2005.
- European grapevine moth (*Lobesia botrana*) was first discovered in California in 2009.
- Kudzu bug (*Megacopta cribaria*) was introduced to the U.S. in 2009.
- Light brown apple moth (*Epiphyyas postvittana*) was introduced into California in 2007.
- Bagrada bug (*Bagrada hilaris*) was first discovered in California in 2008.
- Spotted wing drosophila (*Drosophila suzukii*) was first detected in California in 2008 and has since spread through the West Coast and has been problematic in many states nationwide.

- Brown marmorated stink bug (*Halyomorpha halys*), although detected in 2001, the BMSB has become a serious pest in many Eastern region states (*Figure 7*).

Figure 7.

Brown marmorated stink bug, by Yerpo—own work, *https://commons.wikimedia.org/wiki/File:Halyomorpha_halys_nymph_lab.jpg*.

Insect pests are a major cause of crop losses, with one farmer stating, "There is no organic approved method to control pecan weevil (*Curculio caryae* Horn). This insect will cut my production from 10–35% in most years."

Some topics for future research include:

- Influence of soil components on disease and insect vulnerability.
- Varieties with insect resistance for organic production.
- Impact of rotations and companion crops on insect pressure.
- Beneficial insect habitat through green manures and field borders and other habitat plantings.
- The impact of beneficial insects on crop yields.
- Fly and parasite management practices and their impact on non-target insects (dung beetles, pollinators, *etc.*).
- Control of insects in organic fruits in humid eastern U.S.
- Developing biocontrols for Swede midge (*Contarinaia nasturtii*) (first discovered in the U.S. in 2004) and leek moth (*Acrolepiopsis assectella*).

Economic and Social Science Research

Joanna Ory.

OFRF recommends increased social and economic research to address the marketing challenges experienced by organic farms. Throughout the survey responses, the topic of economic viability of different production practices was a recurring focal area for growers. Farmers expressed the challenges of knowing where to source affordable soil fertility inputs as well as frustration among struggling enterprises to pay their farm crew the fair and livable wages they deserve. Several expressed challenges related to isolation from markets. One farmer stated, "Local people, including restaurants, don't want to pay the organic price for vegetables or hay. We are a small grower but we live within 20 miles of some areas who might pay the price."

Top Areas for Increased Research Related to Organic Marketing and Economics Include

- Research on the different approaches to organic marketing (such as using a CSA, farmers market, cooperative, *etc.*) and the associated costs and benefits.
- Research on reducing high transportation costs, especially for meat producers whose distance from processors makes it difficult to do direct and wholesale marketing.
- Research on how to enter or remain viable in a saturated market.
- Research on how to best educate consumers about different organic practices with the goal of increasing market demand and opportunities.
- Research on how to best educate consumers about the organic label and standards in order to avoid confusion with other labels, such as natural and non-GMO.
- Research on the discrepancies of how animal operations are providing adequate outdoor access, specifically how large operations may be shifting demand from smaller, diversified operations which provide greater outdoor access.
- Research and training for finding buyers who will purchase from small-scale farms or strategies for how small producers can collaborate to approach institutional buyers.

- Research on building markets to help domestic organic farmers compete with inexpensive imports (especially grain).
- Research on how small farms can cope with the pressure to make organic food affordable and the need to receive a fair price.
- Research on how the organic check-off may affect organic farmers of different scales.
- Research on how to create alternative markets for imperfect produce.
- Research on viable price information and market volume data.

Joanna Ory.

GMO Impact on Organic Farmers

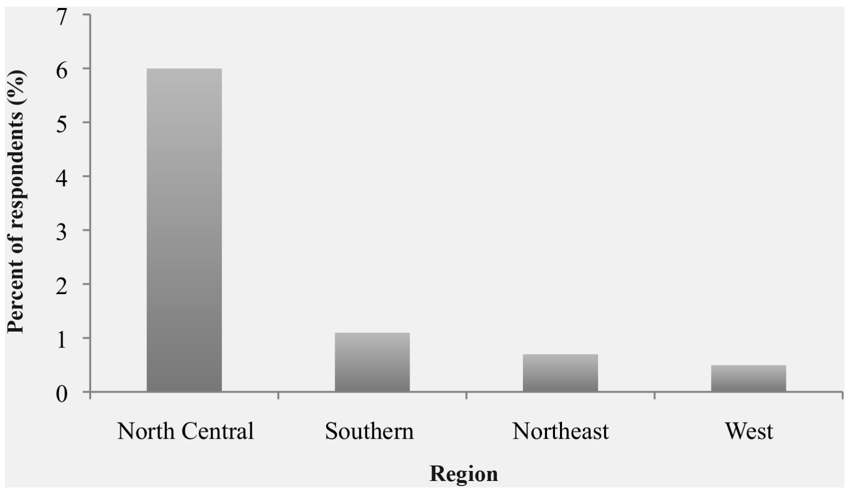
Under the National Organic Program, organic agriculture prohibits the use of genetically modified organisms (GMO). Nationwide, 39.8% of surveyed organic farmers rated the impact of GMO crops on production, practices, sales, markets, and seed availability as a high research priority. Regions in the Midwest where there are more GMO crops grown (like corn and soy) expressed the greatest need for research on GMO impacts.

Farmers stated that there is a need for specific types of research and information on GMO drift and other contamination issues. In addition, farmers stated that there is a need to communicate with conventional farmers about problems of drift without alienating them. One farmer mentioned that there is an opportunity to find solutions to the problem and conflicts surrounding GMO contamination by reinforcing the understanding that both small organic farmers and small conventional farmers make important economic and social contributions to the economic viability of rural communities.

Impacts on Organic Farmers

The survey asked whether organic farmers had experienced GMO contamination and the rejection of a shipment of goods. Nationally, 2.2% of farmers reported having a shipment of product rejected due to GMO contamination (N = 881). However, this rate of contamination is not uniform throughout the U.S. The North Central region had 6% of respondents report having a product shipment rejected due to GMO contamination (*Figure 8*).

Figure 8.

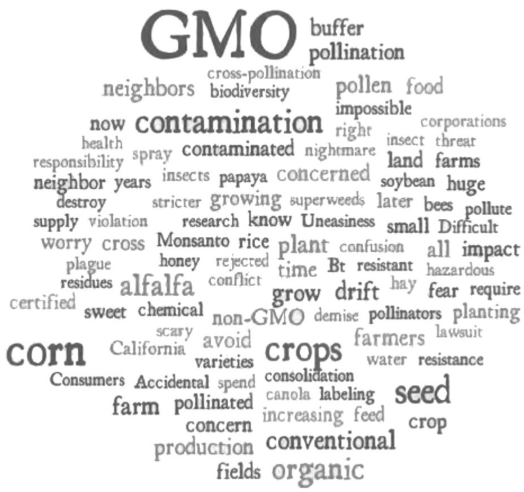


Regional distribution of organic rejections due to GMO contamination (N = 881).

The survey asked farmers to describe the impact GMOs have had on their farm. The responses indicate that in addition to the direct financial impacts of having products rejected as organic, organic farmers expressed a range of different ecological, financial, and psychological impacts they experience from the threat of GMO contamination. The 263 open-ended responses fall into several categories: pollen drift, delayed or altered planting, lost production, environmental pollution, increased pesticide pollution/drift, and psychological/emotional concern.

A word cloud created using keyword counts visually depicts the important terms represented in the survey (*Figure 9*).

Figure 9.



Word cloud for GMO impact open-ended questions.

The size of the word represents the number of times it was mentioned in the survey responses.

Recommendations

Based on the survey data collected and listening sessions, OFRF makes the following recommendations for research:

- Increase research on GMO avoidance practices, especially in the North Central region.
- Increase research and monitoring of the true economic impact of GMOs on organic farmers.
- Increase research on environmental impacts of GMOs.

For the complete discussion of GMO impacts, see *Appendix E.*

Livestock and Animal Agriculture Research Needs

In the U.S., about 120M acres of pasture land (*e.g.,* cultivated or native grassland managed for grazing or forage harvesting) are used by ruminant animals to produce milk, meat, and fiber (NRCS, 2014). In addition, of the more than 100M head of livestock that utilize grazing lands in the U.S., about 45% is concentrated on pasture lands in the humid eastern region of the conterminous U.S. Today, grassland-based agriculture is valued at $44B annually (Natural Resources Conservation Service, 2014).

Forty-one percent (41%) of farmers in the 2015 National Organic Farmer Survey produced animal products, with the most commonly produced animal product being beef followed by poultry and dairy. A commonality among recent surveys and research reports has shown a significant lack of funding related to organic animal agriculture, including OFRF and USDA OREI/ORG programs. The reason for this discrepancy compared to funding for plant related research efforts is unclear. It may be due to a lower number of animal producers as compared to plant producers, the lower number of proposals submitted to funding agencies on animal production topics, or the high cost of animal research. Inherently, it should be noted that crops are part of animal production systems as they are a major feedstuff/input for those systems, so they indirectly benefit from cropping systems.

The Union of Concerned Scientists (UCS) found that the organic dairy sector provides more economic opportunity and generates more jobs in rural communities than conventional dairies. The first-of-its-kind study, "Cream of the Crop: The Economic Benefits of Organic Dairy Farms," calculated the economic value of organic milk production. "Over the past 30 years, dairy farmers have had a choice: either get big or get out. Dairy farmers either had to dramatically expand and become large industrial operations or they went out of business," said Jeffrey O'Hara, agricultural economist for the Food and Environment Program at UCS and author of the report. However, in a summary of work conducted through USDA NIFA, it was found that organic dairy production offers farmers another option—one that is better for the environment, produces a healthier product, and leads to greater levels of economic activity (O'Hara and Parson, 2012).

Organic livestock farmers experience particular issues of concern related to food safety standards, animal health, and veterinarian care. Research needs on organic animal production were assessed at the 2015 Organic Agriculture Research Symposium. The results of a breakout session on animal research needs determined there are several areas in need of prioritization for organic farming. These topics include:

- Efficacy of available treatments, therapies, and approved products.
- Impact of grass-based systems on animal disease (long-term study).
- Incidence of lameness on organic farms, causes, nutrition, symptoms, housing, stress, environment, and preventative practices.
- Breed performance in organic systems (health, pathogens, and parasites).
- Parasite prevention on pastures.
- Poultry breed and ration customization for season/climate, environment, available feeds, pasture, and markets.
- Integrated livestock/crop systems (food safety and pest/disease suppression).
- Effective treatment options for poultry diseases and the interactions with human pathogens.
- Effective alternatives to synthetic methionine.
- Soil health and mineral balancing impacts on animal health, *i.e.,* how to assess holistic impacts/nutritional informatics.
- More research on the economics and efficacy of probiotics for animal health (efficacy, risks, costs/benefits, regulatory status).
- Parasite management for hogs and small ruminants.

Organic Seed Breeding

The 2007 NORA report stated that the organic seed requirement for organically certified crops, combined with increasing risk of organic crop contamination by GM gene sequences, has led to increased interest in organic variety development and seed production on the part of organic farmers. Organic farmers have two distinct needs relating to seed. The first is for well-adapted crop varieties that perform well under organic management; the second is for accessible, affordable, high quality seed that produces what a grower expects it to produce.

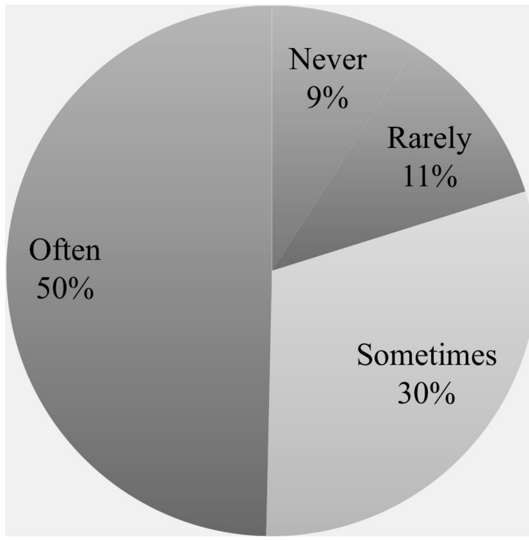
Schonbeck, *et al.,* (2016) indicates that even though classical breeding research for crops and animals has increased over time, there is still a very limited number of breeding programs and a decline in professional researchers in this specialty.

In the 2015 National Organic Farmer Survey, farmers commonly stated the need for increased on-farm plant breeding and variety improvement for organic seeds. Specifically, farmers noted the need to develop more organic hybrids for disease resistance. Farmers also expressed different views related to the policy for organic seed sourcing, especially the need to increase the number of organic seed breeders and distributors.

Organic Seed

According to the National Organic Program guidelines, organic farmers must use organic seed when it is commercially available. However, if the desired organically produced seed or planting stock variety is commercially unavailable, organic farmers may use conventionally grown, untreated, non-GMO seeds. To assess the availability of organic seed, we asked the survey participants to categorize the frequency of organic seed availability for the primary crops they grow. The survey found that for 20% of respondents, organic seed was rarely or never available (***Figure 10***). There were some regional differences. Farmers in the Western region reported less organic seed availability; reporting that organic seed was never available 14% of the time.

Figure 10.



Frequency of organic seed availability as reported by U.S. organic farmers.

Farmers reported several major areas of concern regarding organic seed. The biggest challenge reported was the price of organic seed being much higher than non-organic seed. Other major challenges are the quality and regional and temporal unavailability. As a result of challenges regarding the availability of organic seed, many surveyed farmers reported doing their own seed saving.

One farmer described the disadvantage small organic farmers face with obtaining organic seed in a rural market. The farmer stated, "Many of the large agricultural product cooperatives through which rural people source feed and seed do not carry organic seed as a standard. They require the purchase of a full semi load to even consider making the order. Small- and mid-scale operations struggle to gain affordable access to untreated, non-GMO, and certified organic field seed."

Organic Seed Price

The higher price for organic seed was the most common challenge reported by growers in the survey. The large price discrepancy between organic and conventional seed is a disincentive for farmers to use organic seed. Survey participants stated that high organic seed cost is interfering with profit, and that price is an important factor with regards to seed sourcing. Several farmers also expressed an understanding that the limited number of organic seed distribut[o]rs is helping to create the situation of high prices for organic seed.

Organic Seed Quality

Survey respondents reported that the quality of organic seed was often inferior to conventional seed in terms of germination rate, yield, vigor, and contamination with weed seeds. Respondents also reported that there are fewer organic seed varieties to choose from. Organic farmers need varieties specific to their needs, such as high nutrient-use efficiency, disease resistance, insect resistance, weed competition, and good quality. Although there has been progress in seed breeding for organic production, it is a slow process and some farmers report dissatisfaction with organic seed germination rates.

Organic Seed Availability

Many farmers reported that organic seed was not available locally in their area for certain crops, or became harder to find during the peak of the planting and growing season. There were several crops for which respondents reported very little availability, specifically grass, cover crops, kale, and flower seeds.

Specific Areas of Need

Surveyed farmers highlighted several areas for which there is a need for more research or policy change regarding organic seed. Farmers commonly stated the need for increased on-farm breeding and variety improvement for organic seeds for the development of more organic hybrids for disease resistance. Farmers also expressed different views related to the policy for organic seed sourcing. Several farmers stated the need for stricter enforcement of using organic seed.

For a complete discussion of organic seed issues, see *Appendix F*.

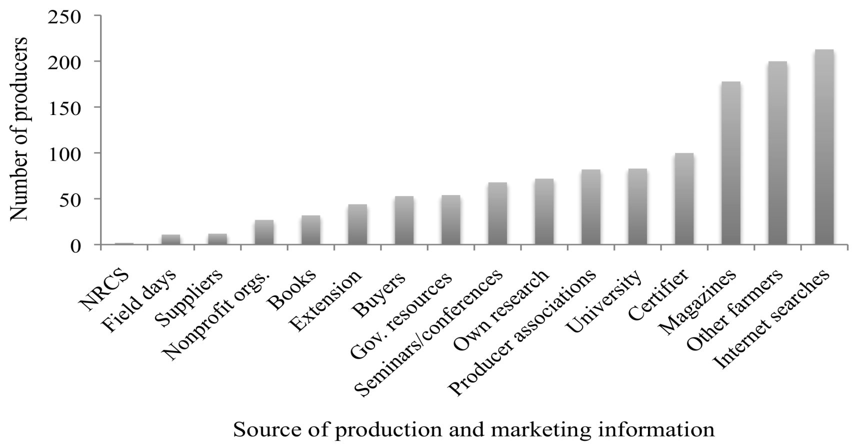
Jack Dykinga.

Information Sources and Formats

The 2015 National Organic Farmer Survey asked participants to list their primary source of organic production and marketing information. Respondents listed many different information sources including the Internet, other farmers, certifiers, chemical companies, seed catalogs, and conferences. Despite having many different resources for organic farming information, several farmers expressed the need for greater availability of organic specific production and marketing information. For example, one farmer stated, "We are lacking of research into our main problems in the Great Northern Plains on the problems that we face in organic agriculture."

Of the farmers surveyed, 902 responded to an open ended question about their primary source of production and marketing information. The top sources of information used in order of their priority are: Internet searches, other farmers, magazines like Acres and Tilth, certifiers, university publications and research, producer association newsletters, and their own research (*Figure 11*). As farmers gain experience, they report moving from learning from books and classes to doing their own research on the Internet and in the field. Because Internet searches are the most used source of information, it is important to strengthen resources like eOrganic and let organic farmers know about reliable data sources and sites where they can exchange information with other farmers.

Figure 11.

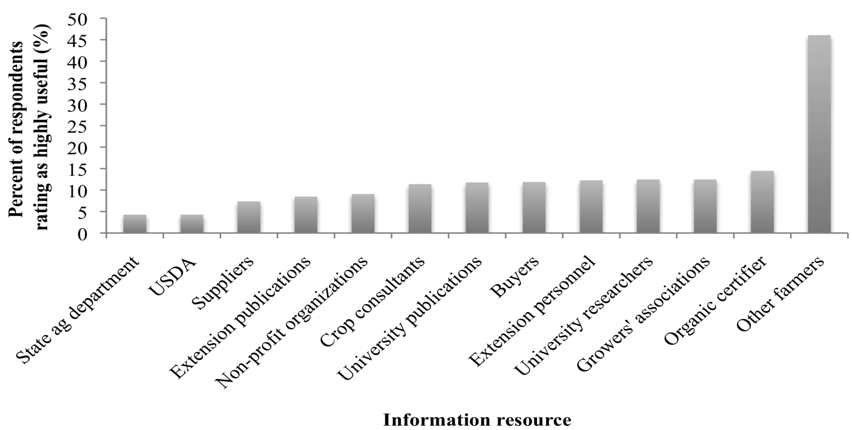


Most used information sources for production and marketing by surveyed farmers.

When asked to rate different information sources based on their usefulness, information from other farmers was listed as the most highly useful information resource (*Figure 12*). For example, one farmer stated, "I get my information from other farmers. Extension is helpful, but usually a bit behind many farmers in assessing production techniques." Another farmer stated that getting information from other farmers has a long history in the development of organic agriculture, "Other farmers who share their experiences—we learn and support one another. When you're developing or on the cutting edge of adopting new practices there isn't research out there to benefit from. Such was the case with organic when we certified 20 years ago—we only had other farmers and our own (expensive) process of trial and error."

Other resources with high scores for being highly useful include organic certifiers, growers' associations and university researchers. Many farmers reported limited use of information from crop consultants and nonprofit organizations.

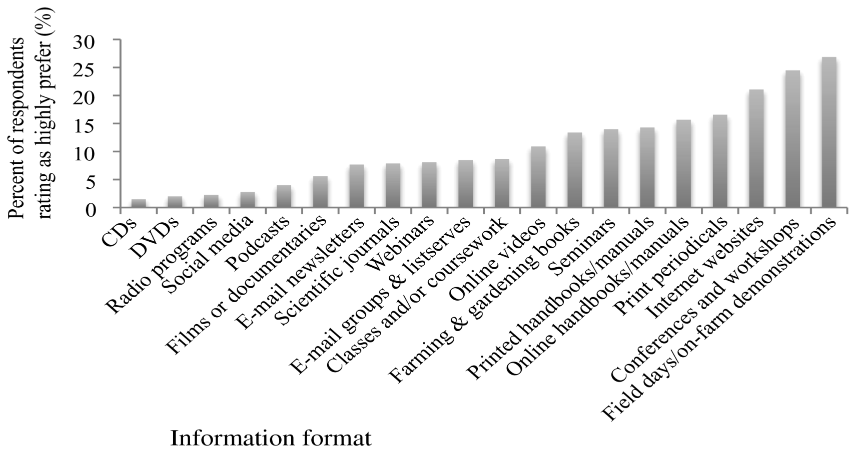
Figure 12.



Respondent rating of high usefulness of different information sources.

Respondents were asked to rate their preferences for different information formats. The respondents listed field days/on-farm demonstrations as the most highly preferred format (*Figure 13*). Other popular formats include conferences and workshops, websites, and print periodicals. Considering this was administered as an online survey, there may be a bias towards online informational resources as the survey does not include responses from farmers who lack Internet access. The preference for field days and conferences indicates that the respondents prefer experiential, in-person learning on organic production and marketing topics.

Figure 13.



Respondent rating of high preference for different information formats.

Regional Results

Production Challenges

In the survey, farmers and ranchers were asked to describe their biggest production challenges. These challenges varied depending on the region (see major challenges for each region below). These challenges are areas for which future research can be prioritized, as they indicate the most difficult obstacles growers face in organic production.

Western Region

- Coping with and adapting irrigation systems to drought conditions.
- Weeds: puncture vine weeds (*Tribulus terrestris*), Johnsongrass (*Sorghum halepense*), and cape ivy (*Delairea odorata*).
- Soil diseases like *fusarium* pathogens.
- Insect pests like Bagrada bug (*Bagrada hilaris*).
- Insufficient animal slaughter facilities.

North Central Region

- Marketing and profitability strategies best suited to organic enterprises.
- Weed management.
- Weather and climate change, *e.g.,* too much rain.
- GMO contamination and avoidance.
- Not enough organic meat processors and USDA meat and poultry inspectors, and how such supply chain barriers can best be addressed.
- Meeting the Food Safety Modernization Act requirement.

Southern Region

- Stink bugs such as the brown marmorated stink bug (*Halyomorpha halys*).
- Johnsongrass (*Sorghum halepense*).
- Lack of accessibility to the commercial market.
- The development of a food safety plan that suits organic production systems well.
- Weather and climate change—heavy rain causing weed and disease problems.
- Profitability and consumer education.
- Lack of reliable labor, of particular import to organics because of increased labor intensity.

Northeast Region

- Maintaining soil health.
- Weed control.
- Animal health, including availability of good pasture and forages.
- Frequent and severe precipitation causing flooding and increased disease.
- High labor and land costs.

Research Priorities

There was regional variance for the top research priorities depending on the production challenges and crops grown in different parts of the country. For example, the Western region rated irrigation and drought management as a top priority, and the North Central region rated research on genetically modified organisms (GMO) contamination as one of the top priorities. Despite these regional differences, the topics of soil health and weed management were consistently top priorities for future research throughout the nation. The list below shows the top high rated priorities with the percent of respondents who marked "high priority" in parentheses.

Western Region

- Soil health, biology, and nutrient management (71%)
- Fertility management (66%)
- Weed management (63%)
- Irrigation and drought management (56%)
- Insect management (56%)

North Central Region

- Soil health, biology, and nutrient cycling (78%)
- Weed management (75%)
- Fertility management (66.6%)
- Nutritional quality and health benefits of organic food (62%)
- Soil conservation and restoration (59%)
- Contamination from genetically modified organisms (GMO) (52%)

Southern Region

- Soil health, biology, and nutrient cycling (79%)
- Weed management (69%)
- Fertility management (67.4%)
- Nutritional quality and health benefits of organic food (66%)
- Insect management (61.9%)

Northeast Region

- Soil health, quality, and nutrient management (74%)
- Fertility management (66%)
- Weed management (61%)
- Nutritional quality and health benefits of organic food (51%)
- Pollinator health (48%)
- Soil conservation and restoration (48%)

3. Discussion and Supplemental Reviews

To inform the recommendations in this NORA report, OFRF reviewed USDA funded research, results from other surveys, OFRF funding programs, and recommendations from other organizations such as the National Organic Standards Board (NOSB).

OFRF reviewed USDA OREI and Organic Transitions (ORG) funded programs between 2002 and 2014, to evaluate what research, education, and extension projects had been funded. Research recommendations from that review have been evaluated in reference to the research objectives identified by farmers and ranchers in the 2015 National Organic Farmer Survey

In addition to national reviews, OFRF has conducted internal reviews of research funded since the beginning of the OFRF competitive grants program in 1992. Relevant research recommendations have been provided based on gap analysis of not only what was funded, but also the priorities for future funding needs. The first review was *Investing in Organic Knowledge, Impacts of the First 13 Years of the Organic Farming Research Foundation's Grantmaking Program* (Sooby, 2006). The most recent report was the *Trends and Impacts of the Organic Farming Research Foundation Grants Program: 2006–2014* (Ory, 2015). This report provides an analysis of 106 OFRF-funded projects that have had positive impacts on organic farming in many areas. From research projects examining new varieties and organic seed breeding, to educational projects that link beginning farmers with mentors, OFRF grants have helped produce important tools and informational sources for organic farmers.

Review of USDA Funded Research on Organic Farming

The *Report and Recommendations on Organic Farming* issued by the Organic Study Team in 1980, provided an initial review of organic programs within the USDA. The report acknowledged that the USDA knew very little scientifically about organic agricultural productivity, much less about the economic benefits and costs of organic farming (USDA Study Team on Organic Farming, 1980). A dominant question posed by the Study Team was, "Under what specific circumstances and conditions can organic farming systems produce a significant portion of our food and fiber needs?" Now that organic agriculture is an established part of U.S. and international diets, it is clear there is a need to increase organic production worldwide. Not only is research on organic methods and practices important to organic producers, it is also relevant to conventional producers as they may adopt many of the fundamental organic practices to meet environmental and societal goals for agricultural sustainability (USDA Study Team on Organic Farming, 1980).

Since the 2007 NORA report (Sooby, *et al.,* 2007), USDA investment in organic research has increased. In 2016, OFRF conducted a review of the USDA OREI and ORG organic grants programs titled, *Taking Stock: Analyzing and Reporting Organic Research Investments, 2002–2014.* This report examines the research, education, and extension areas that have been funded and those that have been underserved (Schonbeck, *et al.*, 2016). The majority of funded projects related to crop instead of animal systems with 91% studying crops and 25% researching animals (some projects included both). Only 6% of awards went to animal system projects. Similar to the NORA report, *Taking Stock* recommends increased research on animal health, organic plant breeding, soil quality and weed management, as well as pollinators and pollinator habitat. In addition, *Taking Stock* recommends that USDA:

- Continue funding priorities identified in the 2007 and 2016 NORA reports, especially on the topic of organic weed control, soil health and fertility, and co-management of weeds, nutrients, and soil health.
- Increase research on organic livestock production systems, especially pork, beef, and turkey.
- Increase funding for historically underrepresented commodities such as rice, cotton, tree nuts, and cut flowers.
- Invite and fund proposals on functional agricultural biodiversity, and practical strategies for different regions to meet the National Organic Program (NOP) requirement to conserve biodiversity and use cover crops.
- Fund meta-analyses of outcomes of multiple OREI and ORG projects on complex topics such as soil quality/weed co-management; and carbon sequestration/net greenhouse gas impacts of different systems; and the challenges of dryland organic production in semiarid regions.

Although advances have been made, organic agriculture research remains underfunded and requires greater commitment by funding agencies. OFRF recommends significant increases in USDA funding for organic agriculture research in order to implement the recommendations of both this NORA report and the *Taking Stock* report.

Review of OFRF Surveys and Reports

OFRF has published several national farmer surveys and reports to assess farmer needs and advocate for better policies. The 2007 NORA report had a significant influence on the dramatic expansion of Federal organic research funded through the Food, Conservation and Energy Act of 2008, commonly known as the 2008 Farm Bill. It also helped guide OREI program priorities and was widely cited in applications to the USDA OREI program as justification for specific research projects.

Since the 2007 NORA report, the research community has focused and contributed knowledge in several key areas. For example, there have been new successes in organic plant breeding, including the development of several varieties of open-pollinated sweet corn. In addition, many OREI projects funded by the USDA addressed issues of organic soil health and fertility, a top priority identified in the 2007 NORA report.

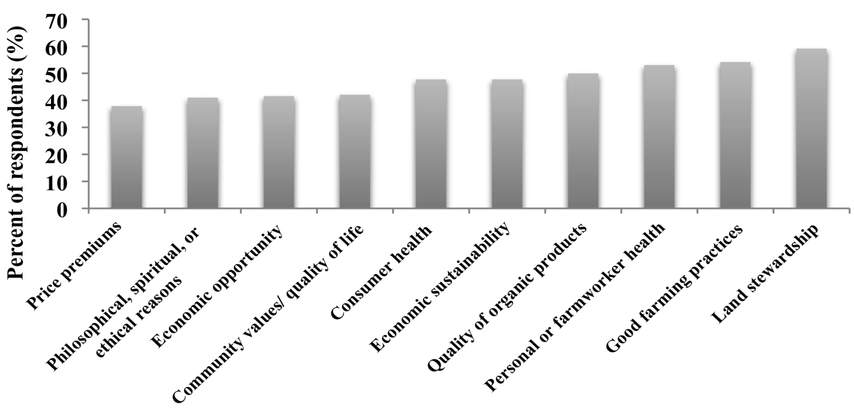
Even with increased attention to key organic priority areas, many of the recommended areas for research require continued attention from the research community. The 2015 National Organic Farmer Survey results show that soil health and applied research for weed and pest management are the highest priorities for organic research.

Soil organic matter, fertility, and microbial impacts are identified as needs in both reports. Weed pressure remains a major concern for farmers and ranchers, as well as appropriate control measures, efficacy of control products, and effects of different tillage practices. Major outbreaks of specific insect pests may have changed, but insect and disease control research needs are of high priority, especially in more humid and warm geographic areas. Since the 2007 NORA report was released, there are several new insect pest species that affect organic growers, like Bagrada bug (*Bragda hilaris*), Asian citrus psyllid which transmits citrus greening disease, and Light Brown Apple Moth (*Epiphyas postvittana*).

Animal systems research has been limited in past research efforts, and the specific needs for nutritional studies, pasture management, and breeding remain high priorities.

A survey of organic farmers conducted in 2011 by OFRF provides complementary information to the 2015 National Organic Farmer Survey regarding why organic farmers choose to become organic. The survey asked 422 farmers to rate the importance of the reasons they became organic farmers. The reason most commonly rated as very important was land stewardship, and the reason least commonly rated as very important was price premiums for organic products (*Figure 14*).

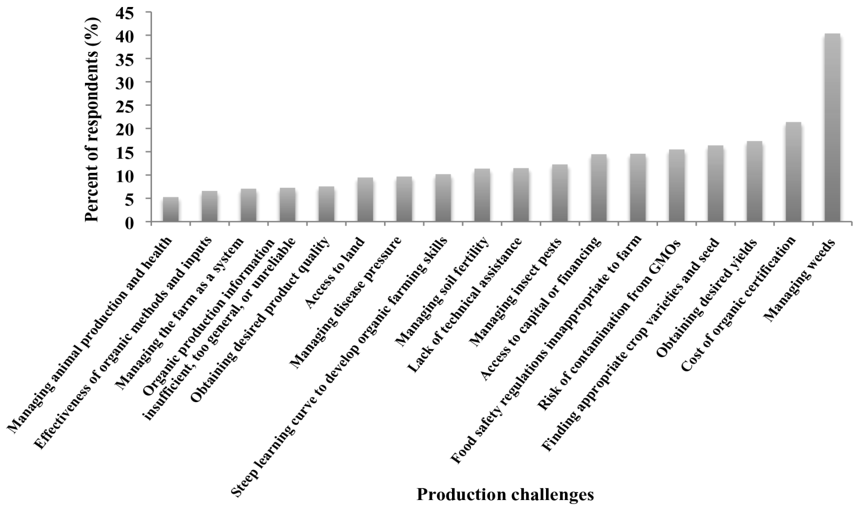
Figure 14.



2011 Survey results on why farmers became organic.

The 2011 farmer survey found that the production challenge most rated as a strong challenge was weed management (*Figure 15*). This finding of weed management as a top priority was reinforced in the 2015 National Organic Farmer Survey with weed, pest and disease management rated the top research priority by 39% of respondents. Other top challenges in 2011 included finding organic seed and the cost of organic certification. The USDA is now providing payment support for initial certification costs through the National Organic Certification Cost Share Program (NOCCSP) and the Agricultural Management Assistance (AMA) Organic Certification Cost-Share Program. These programs provide a combined $11,632,000 in assistance in 2016 (USDA, 2016 b, *https://www.ams.usda.gov/services/grants/occsp*). During FY 2012, 7,245 producers received assistance from the NOCCSP and 2,348 received assistance from the AMA (*https://www.ams.usda.gov/sites/default/files/media/2013OCCSPReport%20to%20Congress.pdf*)

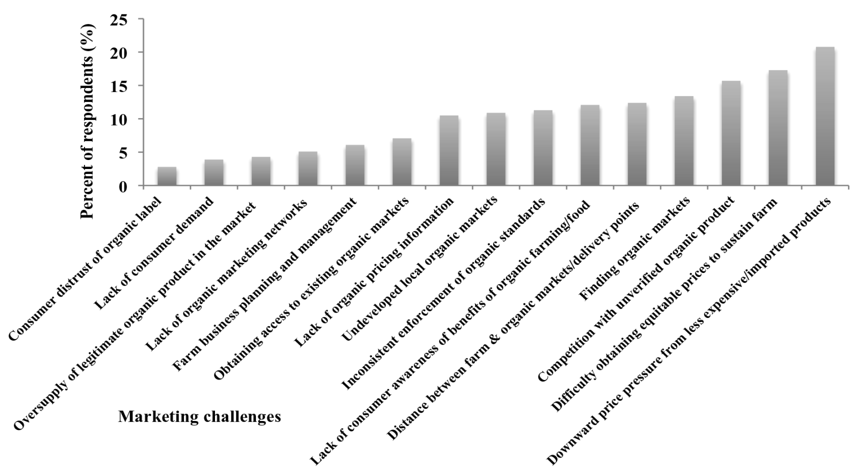
Figure 15.



2011 survey responses on top production challenges.

In the 2011 survey, the marketing challenge most rated a strong challenge was downward price pressure from less expensive or imported products (*Figure 16*). The competition of less expensive/imported products was rated a strong challenge by 21% of respondents, demonstrating that importation of organic products is a major concern for U.S. farmers. Other top challenges included the difficulty of obtaining sufficient prices for sustaining the farm, and competition with "unverified" organic product.

Figure 16.



2011 survey responses on top marketing challenges.

The 2011 National Organic Farmer Survey gave important background on the different production and marketing challenges of organic growers. The 2015 National Organic Farmer Survey builds off this information by focusing on the specific current research needs of organic growers.

The 2015 National Organic Farmer Survey and listening sessions highlighted some of the most pressing economic, social, and marketing challenges and research needs of organic farmers, an area that was not well developed in the 2007 report. The information in the 2011 survey on marketing challenges provides support for the recommendations in the 2016 NORA Report to increase consumer education and economic and marketing research.

Overlap of OFRF and NOSB Recommendations

The NOSB is a Federal Advisory Board that makes recommendations regarding the production, handling and processing of organic products. Attention to production issues as they relate to evolving organic standards is an important area of research. OFRF recommends strengthening the communication channels between the NOSB, NOP, and the research community in order to provide growers with information and recommendations in advance of phasing-out a previously approved substance. (*www.ams.usda.gov/rules-regulations/organic/nosb/recommendations*)

NOSB created a list of research recommendations, mostly related to the organic certification standards which were presented to the NOP in 2015 (AMS, 2015; *https://www.ams.usda.gov/sites/default/files/media/MS%202015%20NOSB%20Research%20Priorities_final%20rec.pdf*). The 2015 National Organic Farmer Survey results support many of the NOSB recommendations, including:

- Increased research on field management practices for organic whole farm systems.
- Increased research on organic plant and animal breeding.
- Appropriate product reviews for toxicity and efficacy of NOP approved products, including food additives and food packaging products.
- Increased research on the effects of GMO materials, including GMOs in organic compost.
- Increased research on organic livestock systems, including animal herd health, parasite treatment and avoidance, and animal nutrition.

In addition, OFRF recommends increased research to support improved clarity in the standards that govern animal welfare on organic farms. The 2015 National Organic Farmer Survey respondents and listening session participants stressed the need to verity the efficacy of products and practices used by producers and approved by NOSB.

The 2015 National Organic Farmer Survey results indicate a concern regarding GMO contamination (see GMO critical issues section). OFRF is in agreement with NOSB that research to prevent GMO contamination is a high priority. Specific topics for future research include: evaluation of effectiveness of prevention practices (cleaning equipment, creating buffer rows, maintaining seed purity, reducing spread of GMO pollen by pollinators.) In addition, research on practices conducted by conventional growers to determine where GMO contamination is coming from, is a valuable research area. Other NOSB recommendations that complement OFRF recommendations include:

- Comparing till and no-till practices related to soil health, level of soil organic matter, biodiversity, fertility, weed control, and pest management.
- Finding effective alternatives to allow eliminating the use of antibiotics for plant disease control and animal production.
- Finding alternative plant disease management practices and materials, especially in humid (*i.e.,* Southern region) areas.
- Increasing information on biological control of plant diseases and bio-pesticides.

Conclusion

This report demonstrated the importance of monitoring the needs of organic farmers. OFRF is committed to our ongoing effort of communicating the research needs of organic farmers to the policy and research communities. We encourage the funding of projects that have solving farmer needs at the core of the research questions and full farmer participation in the research process.

This report contains recommendations for future research to be put into action by the USDA and the broad agricultural research community. Greater regional and Federal funding will be necessary to achieve the growth of organic agriculture and the associated environmental and social benefits.

We encourage policy makers and researchers to use the findings in this report to work towards funding and conducting research projects that will solve the challenges faced by organic farmers.

Results from the 2015 Survey of Organic Farmers and listening sessions provide insights into the most pressing challenges and topic areas that require additional research and outreach. Increased funding for research on critical issues related to soil health and fertility, weed control, invasive insect pests and the nutritional quality of organic food will provide organic farmers with knowledge and tools to enhance their production and marketing. In addition, areas of particular concern to organic farmers, such as GM crop contamination and climate change, warrant increased attention. The survey results highlighted the opportunity for farmer-to-farmer learning, field days, and online resources to increase farmer learning and the application of research results. Through greater extension and outreach to the organic sector, organic farming will benefit from information and guidance that supports the most environmentally and economically sustainable agricultural production systems.

Citations

Greb, Peggy, Canada thistle (*Cirsium arvense*).

Hollinger, Jason, Bindweed (*Convolvulus arvenis*).

Huffington, Matt, Spotted wing drosophila (*Drosophila suzukii*).

Lipson, 1997. *Looking for the 'O' Word.* Organic Farming Research Foundation, Santa Cruz, CA.

Marose, Betty. 2016. Jimsonweed. University of Maryland Extension. National Organic Coalition. 2016. *Organic Research. www.NationalOrganicCoalition.org*.

Natural Resources Conservation Service. 2014. *National trends and resource concerns in managing grazing land ecosystem services.* September 2014, USDA, Washington, D.C.

NOAA National Centers for Environmental Information. 2016. *State of the Climate: Global Analysis for December 2015,* published online January 2016, retrieved on February 3, 2016 from *http://www.ncdc.noaa.gov/sotc/global/201512*.

Northeastern IPM Center, 2016. *Stop BMSB: Biology, ecology, and management of brown marmorated stink bug in specialty crops. www.stopbmsb.org*.

O'Hara, J. and Parson, R. 2012. "Cream of the Crop: The Economic Benefits of Organic Dairy Farms." Union of Concerned Scientists, Cambridge, MA.

Ory, J. 2015. *Trends and Impacts of the Organic Farming Research Foundation Grants Program: 2006–2014.* Organic Farming Research Foundation, Santa Cruz, CA.

Organic Trade Association. 2016. *US organic state of the industry. http://ota.com/sites/default/files/indexed_files/OTA_StateofIndustry_2016.pdf*.

Pomplid, Palmer *amaranth pigweed.*

Schonbeck, M., Jerkins, D., Ory, J. 2016. Taking Stock: Analyzing and Reporting Organic Research Investments: 2002–2014. Organic Farming Research Foundation, Santa Cruz, CA.

Sooby, J. 2006. Investing in Organic Knowledge, Impacts of the First 13 Years of the Organic Farming Research Foundation's Grantmaking Program. Organic Farming Research Foundation, Santa Cruz, CA.

Sooby, J., Landeck, J., and Lipson, M. 2007. 2007 National Organic Research Agenda. Organic Farming Research Foundation, Santa Cruz, CA.

Sustainable Agriculture Research & Education (SARE). 2016. SARE's Four Regions. *www.sare.org/ About-SARE/SARE-s-Four-Regions*.

Svoboda, M. 2016. U.S. drought monitor. The National Drought Mitigation Center, Lincoln, NE, Retrieved on Feb. 3, 2016 from *http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CAhttp://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA*.

UC IPM. 2016. *Harlequin bug-**Murgantia histrionica.** ipm.ucanr.edu/PMG/GARDEN/VEGES/PESTS/harlequinbug.html*.

USDA. 2013. *USDA AMS National Organic Program Cost-Share Programs Report to Congress.* USDA, Washington, D.C.

USDA. 2014. *Socially disadvantaged farmers: race, Hispanic origin, and gender.* USDA ERS.

USDA, 2014. *2012 Census of Agriculture.*

USDA. 2016 a. *2015 Certified Organic Survey.* National Agricultural Statistics Service, USDA. Washington, D.C.

USDA. 2016 b. *Organic Certification Cost-Share Programs. https://www.ams.usda.gov/services/grants/occsp*.

USDA Study Team on Organic Farming. 1980. *Report and Recommendations on Organic Farming.* USDA, Washington, D.C.

Vicente Selves, Victor M., Coryneum blight (pathogen *Wilsonmyces carpophilus*).

Appendix A: Western Region

Introduction

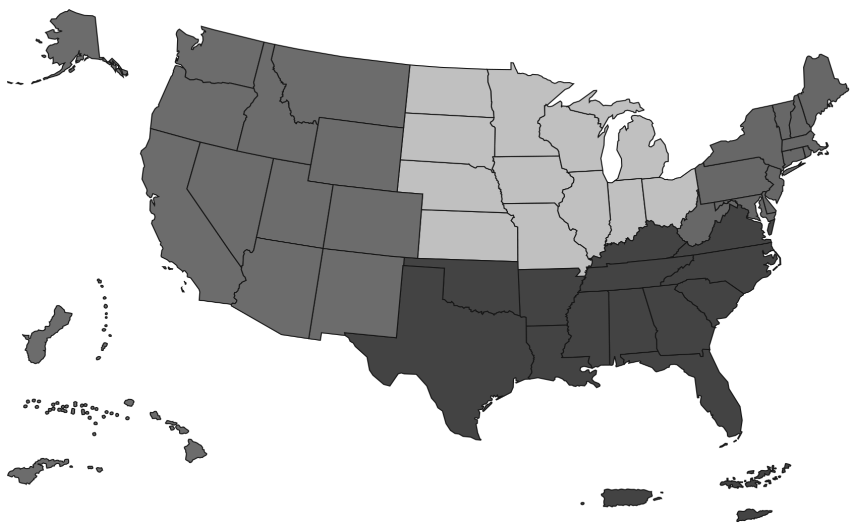
The Western region includes Alaska, American Samoa, Arizona, California, Colorado, Guam, Hawaii, Idaho, Micronesia, Montana, Nevada, New Mexico, N. [Mariana] Islands, Oregon, Utah, Washington, and Wyoming (see blue region on map; *Figure A.1*). The Western region is a leader in organic production with four states (California, Washington, Oregon, and Colorado) in the top ten U.S. states for organic product sales (USDA, 2015).

Research, Extension, and Educational Recommendations for the

Western Region

- Provide beginning and transitioning farmers and ranchers the tools, knowledge, and on-going mentoring to be successful organic producers.
- Prioritize research on water management in drought conditions, water efficiency technologies, and innovations for drought management.
- Continue long-term research on soil health with focus on nutrient and water management.
- Prioritize research on organic production practices that can increase carbon sequestration. Current research shows that organic soils with higher soil organic matter can increase the sequestration of carbon in the soils.
- Prioritize research on weed control. Weed control continues to be an area where research can benefit more sustainable weed control practices, especially for resistant and invasive weeds. Efficacy of organic products will also benefit the farmers as they select efficient and cost-effective products. Tillage and plant and animal rotations are of special interest.
- Invest in research on disease and pest problems of high importance in California. In addition to general research on specific insect controls, continued efforts in breeding specific for organic production and management of these issues will increase productivity and economic viability of organic producers.
- Increased research and extension efforts need to be provided for all aspects of animal production, especially information for rotational and grass fed animals. California is a major producer of milk products and organic livestock and poultry.

Figure A.1.



Western region in blue (SARE, 2015).

The Organic Farming Research Foundation (OFRF) conducted a nationwide survey of organic farmers to identify their research needs. Three hundred and ninety-seven organic farmers from the Western region completed the survey. This report is based on their responses.

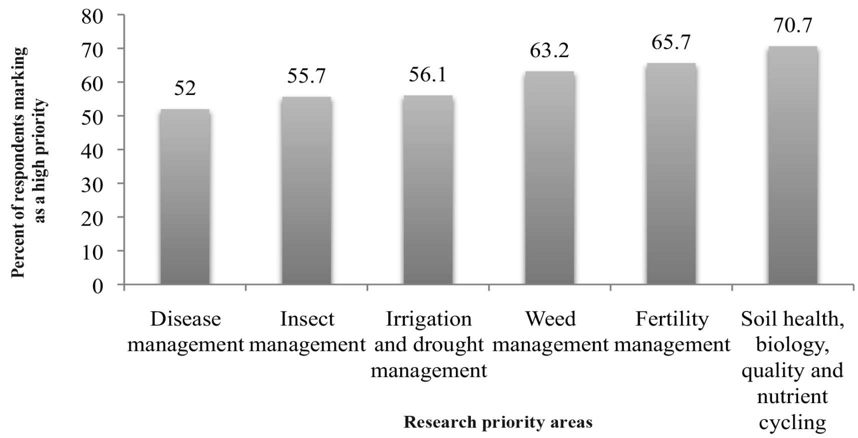
Organic Farmer Survey Results

Western farmers who participated in the survey ranged from having 1 year of organic farming experience to those who have been farming organically for more than 50 years. The size of the organic farms ranged from less than a tenth of an acre to over 20,000 acres. Forty-six percent of farmers surveyed transitioned to organic farming from conventional farming practices, and 48% began farming using organic practices. While 98% of the survey respondents had at least part of their land certified organic, many farmers also had uncertified acres under organic production and acres in transition to organic production. Twenty-seven percent of respondents had a mix of acres under organic and conventional production. CCOF was the certifier for 40% of the survey respondents. Other top organic certifiers included Oregon Tilth, the Washington State Department of Agriculture, the Colorado Department of Agriculture, and the Idaho Department of Agriculture.

Top Research Priorities for the Western Region

The highest priority identified for research in the Western region was soil health, quality, and nutrient management, which was rated as a high priority by 70.7% of respondents. Other top research priorities in order of importance included: fertility management, weed management, irrigation and drought management, insect management, disease management, and the nutritional quality and health benefits of organic food (*Figure A.2*).

Figure A.2.



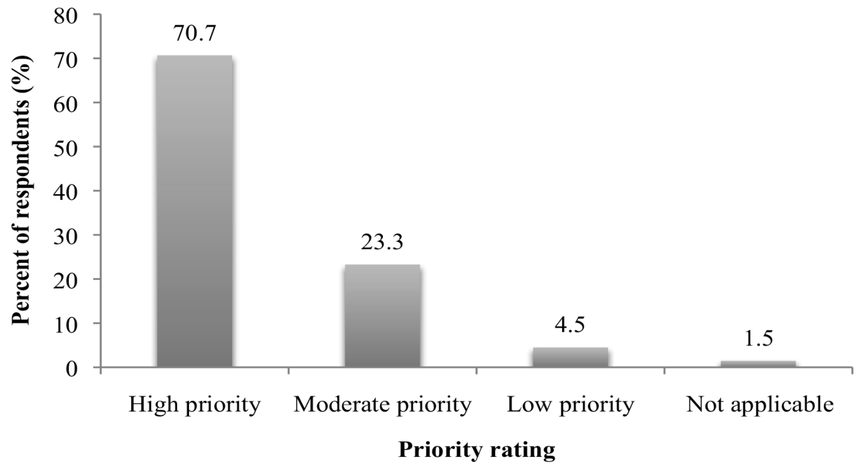
Top six research priority areas identified in the OFRF survey of organic farmers in the Western Region.

Soil Health, Biology, and Nutrient Cycling

Research on soil health was identified as a high priority by 70.7% of respondents (*Figure A.3*). A common theme for transitioning growers is the need for cost effective ways to "jump-start" soils that have been weathered from conventional production practices. Survey respondents reported the need for research on:

- How to maintain and enhance soil biology while using standard tillage.
- How to maintain and enhance soil biology while using minimal tillage.
- How to bring health to soils that were degraded by conventional agriculture.
- The role of tillage in the ability of soil to sequester carbon.
- Best ways to add organic matter to soil with minimal or no till practices for commercial scale.
- How to design diverse cropping systems to optimize soil health. Impact of specific crop and crop mixes on soil biology.
- How to remediate glyphosate residue in the soil profile.
- Building soil health via cover cropping with limited water.
- How to measure the health of the soil microbiome and how soil microbes influence crop health.

Figure A.3.



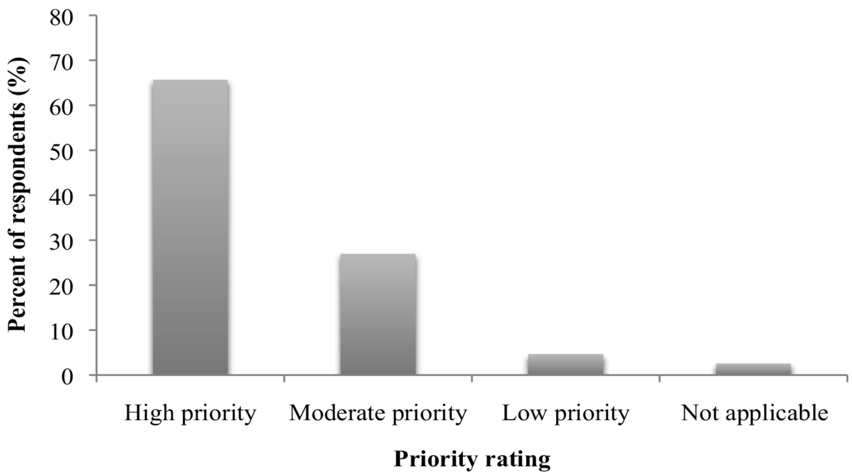
Priority rating of research on soil health by Western region organic farmers in 2015.

Fertility Management

Research on fertility management was identified as a high priority by 66% of respondents (*Figure A.4*). Survey respondents reported the need for research on:

- Microorganisms and fertility.
- Cover crops for building fertility in perennial crops.
- Nitrogen-fixing cover crops for the arid west, specifically for use in surface/subsurface drip irrigation systems between beds.
- Research related to biology and nutrient cycling for a desert climate.
- Nutrients added by sheep grazing in winter, specifically nitrogen (N).
- Soil fertility for organic apples.
- How much fertilizer should be used when, and in what form?
- Liquid fertility management techniques also important to reduce leaching of N.
- Research on varieties that require less fertility inputs and compete better with weeds.
- Organic seed production, use of poultry in rotation to build soil fertility.

Figure A.4.



Priority rating of research on the soil fertility management by Western region organic farmers in 2015.

Weed Management

Weed research was a high priority for 63% of respondents (*Figure A.7*). Farmers expressed the need for solutions to weed challenges, such as optical weeding research and organic herbicides. One farmer stated, "We are losing organic farmers due to field bind weed. It will be vital to organic farming in this area to have some way to eradicate this weed. Disking only slows it down." Common problematic weeds in the Western region include: field bindweed (*Convolvulus arvensis*) (*Figure A.5*), Canada thistle (*Cirsium arvense*) (*Figure A.6*), common lambsquarters (*Chenopodium album*), Bermudagrass (*Cynodon dactylon*), yellow foxtail (*Setaria lutescens*), johnsongrass (*Sorghum halepense*), nutsedge (*Cyperus esculentus*), houndstongue (*Cynoglossum officinale*), common cocklebur (*Xanthium pennsylvanicum*), hawkweed, puncture vine weeds, and cape ivy (*Delairea odorata*). Some farmers also reported what is working for them in terms of weed control. For example, one farmer stated, "Cows for grass between the trees, goats for star thistle and berry vines coupled with our dry farming practices has resulted in a strong grove with many less issues than our neighbors."

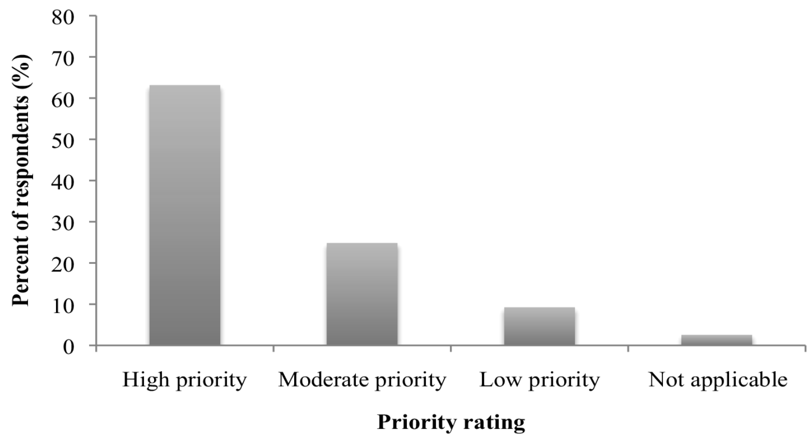
Figure A.5.

Bindweed (*Convolvulus arvenis*) (Photo: Jason Hollinger)

Figure A.6.

Canada thistle (*Cirsium arvense*) (Photo: Peggy Greb)

Figure A.7.



Priority rating of research on weed management by Western region organic farmers in 2015.

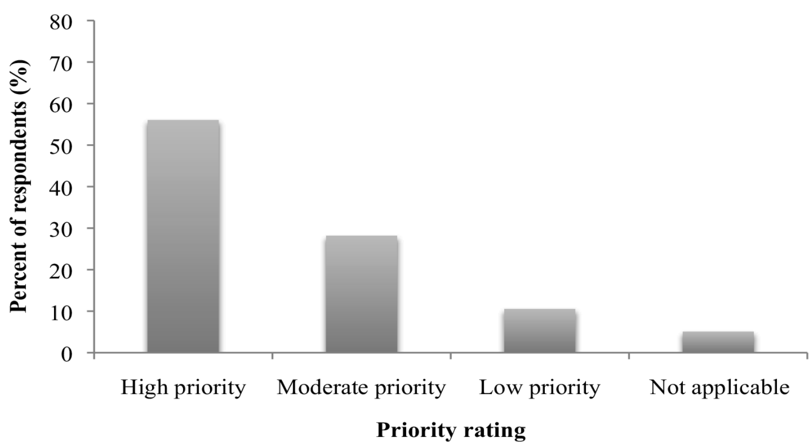
There was substantial interest in the role crop and livestock rotation management could play in weed control. Survey respondents reported the need for research on:

- Using animals to manage weeds, disease and pests and the effect animals might have on these types of management.
- Rotation strategies to decrease annual weed pressure.
- Rotation/tillage strategies or organic approved materials to eliminate bind weed.
- Weed tillage to benefit soil. Reducing the cost of weed control.

Water and Drought Management

As of January 2016, California has been in drought for over 4 years. Other areas of the arid West also struggle with having a reliable water supply for agriculture. One farmer stated, "Drought conditions, increased temperatures, long 'over 90°' heat waves, and the cost/time involved in mitigation has me concerned that I can no longer do this cost effectively." The topic of water management, irrigation, and drought was rated a high priority by 56% of Western region farmers (*Figure A.8*).

Figure A.8.



Priority rating of research on the drought by Western region organic farmers in 2015.

Many growers, especially those in California, listed the impact of the drought as their biggest production challenge. Growers also expressed concern about weather fluctuations and unpredictability caused by climate change.

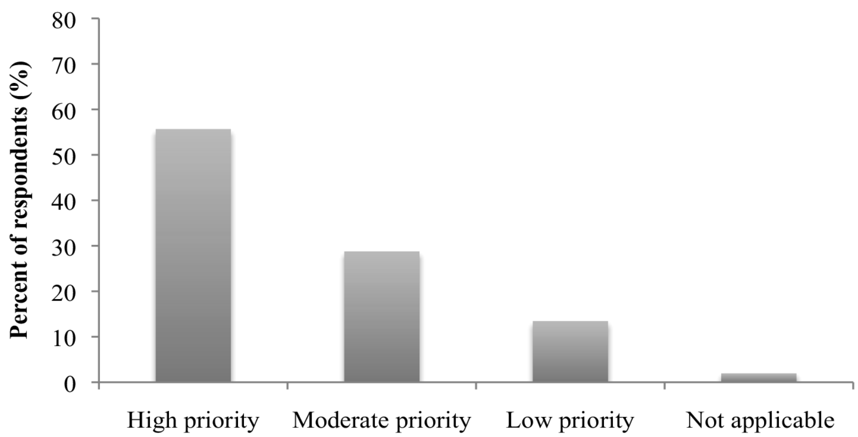
"Weather, particularly drought issues are our most pressing concern. However, 3 years ago we were faced with the issues associated with drowning rain and lack of sunshine. We seem to be swinging between extremes annually. This June our weather was a 1 in 400 year drought." Survey respondents reported the need for research on:

- Tracking water quantity, increasing soil water retention, water storage grant funding, and design for drought resistance.
- Coping with high salinity soils due to drought.
- Absorption and soil moisture maintenance.
- The impact of drought on pasture management (both soil and grass health).
- Increasing compost to reduce water use.
- The correct timing and type of irrigation (drip *versus* sprinkler) to reduce water use.
- Drought and pasture management.
- The effects of drought on soil and grass health.

Insect and Pest Management

Research on insect management was identified as a high priority by 56.3% of respondents (*Figure A.9*). Specific insect pests identified in the survey included bagrada bug (*Bagrada hilaris*), vine mealybug (*Planococcus ficus*), lygus bug (*Lygus Hesperus*), codling moth (*Cydia pomonella*), peach twig borer (*Anarsia lineatella*), wooly aphids (subfamily: *Eriosomatinae*), black cherry aphid (*Myzus cerasi*), cherry fruit fly (*Rhagoletis indifferens* Curran), filbertworms (*Cydia latiferreana*), olive fruit fly (*Bactrocera oleae*), aphids, wireworms, spotted wing drosophila (*Drosophila suzukii*) (*Figure A.10*), and alfalfa weevil (*Hypera postica* Gyllenhal).

Figure A.9.



Priority rating of research on insect management by Western region organic farmers.

New Pests of Interest

Survey participants listed management challenges with several new pests of interest that have recently become invasive in Western region states. There is a special need for research on these pests. Below are a few examples that were listed in the survey as top pests. A full list of invasive insect pests is available through the UC IPM Program at: *http://www.ipm.ucdavis.edu/EXOTIC/*.

Figure A.10.

Spotted wing drosophila (*Drosophila suzukii*) (Photo: Matt Huffington).

The Asian citrus psyllid (*Diaphorina citri*)—Since 2008, the Asian citrus psyllid has been present in California, and there is concern that it will spread to other Western region states. The Asian citrus psyllid can ultimately kill citrus trees by infecting the tree with toxic bacteria.

Polyphagous shot hole borer (*Euwallacea* sp.)—This is a type of ambrosia beetle that has been prevalent in Southern California since 2010. It attacks over 200 tree species and can cause severe damage by infecting them with Fusarium fungus.

Bagrada bug—The bagrada bug was found in June 2008 in southern California, and it has now become a major problem throughout southern California and southern Arizona. Bagrada bug is a pest of crop plants in the *Brassicaceae* (*Cruciferae*), which includes important foods like cabbage, kale, turnip, cauliflower, mustard, broccoli, and radish.

Survey respondents reported the need for research on:

- Effective controls to supplement current organic pest control products to avoid resistance.
- Citrus and wine grape insect control.
- Natural enemy introduction.
- Influence of changing climate on insect pests.
- Crop management to encourage beneficial insects.
- The use of organic insecticides.

Other Pests

Respondents reported problems with symphylans, voles, gophers, moles, squirrels, frogs and birds.

Disease Management

Research on disease management was identified as a high priority by 52% of respondents (*Figure A.12*). Several diseases were identified as a concern for Western region organic growers, including fusarium wilt (*Fusarium oxysporum*), charcoal rot (*Macrophomina phaseolina*), curly top virus, downy mildew (example: *Peronospora farinosa*), powdery mildew (example: *Podosphaera xanthii*), Pierce's disease (*Xylella fastidiosa*), verticillium wilt (*Verticillium* spp.), phytophthora (*Phytophthora* spp.), fireblight (*Erwinia amylovora*), coryneum blight aka shothole blight (*Wilsonmyces carpophilus*) (*Figure A.11*), *Pseudomanas syringae,* peach brown rot (*Monilinia fructicola*), and botryosphaeria canker (*Botryosphaeria* spp.).

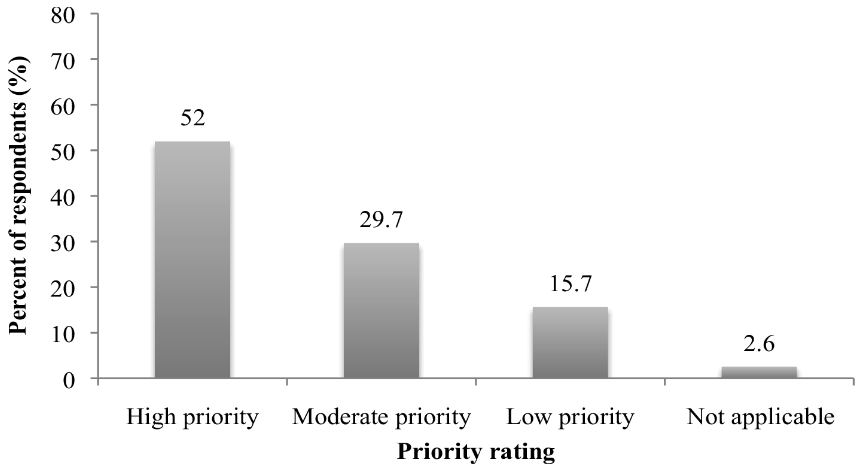
Figure A.11.

Coryneum blight (pathogen *Wilsonmyces carpophilus*) on the leaves and stems of orchard trees (Photo: Victor M. Vicente Selves).

Specific disease issues noted in the survey include:

- Soil disease and nematode control.
- Plant breeding for disease resistance.
- Disease resistant rootstocks for avocado, citrus, and grapes.
- Disease control research for peaches, basil, tomatoes, grapes, and kiwis.

Figure A.12.



Priority rating of research on the disease management by Western region organic farmers in 2015.

Animal Agriculture

Survey respondents noted several areas related to animal health and production for additional research. Food safety and the new requirements of the Food Safety Modernization Act are a topic of concern for many growers.

> *"We have been USDA certified now for 3 years and have had to fight to maintain our livestock on the farm each year. We have decided to quit growing leafy greens and other crops that keep hitting the news with food scares. We have been able to maintain our tree crops as food safety certified because these crops do not come into contact with the ground. The food safety regulations are totally against integrated crop-livestock operations, which have so much potential to stabilize farm income and provide a great agronomic program as well."*
>
> Western region respondent.

Survey respondents reported the need for research on:

- The causes of food poisoning related to processing, handling and packaging on an industrial scale.
- How to reduce or eradicate plant species that the cattle cannot eat.
- How to get the best marbled meat through genetics.
- What is the most efficient and, cost-effective way to get the most out of our pasture while keeping it healthy and productive?
- An effective way to discourage flies on the cattle's face.
- Protection against pathogens such as *E. coli, Listeria,* for grazing animals.
- Research on integrated crop-livestock farming in arid climates, examining both economics and agronomics.
- Comparisons of USA beef and imported beef.
- Information on the nutritional benefits of grass-fed organic beef.

Conclusions and Recommendations

Survey and listening session participants raised the need for research on broad-scale questions, such as the difference between organic and conventional production in terms of the impacts on water quality, biodiversity, and ecosystem health. Based on the responses, more research and education should be focused on:

- Providing beginning and transitioning farmers and ranchers the tools, knowledge, and ongoing mentoring to be successful organic producers.
- Prioritizing water management in drought conditions for Western region growers. Research on water efficiency technologies and innovations for drought management are of high priority for organic farming.

- Continuing long-term research on soil health focused on nutrient and water management.
  - Current research shows that organic soils with higher soil organic matter can increase the sequestration of carbon in the soils. Additional research needs to improve production practices that can increase sequestration levels. This increase can lead to increases in soil organic matter levels and economic benefit to the producer through carbon credits.
- Controlling weeds. Weed control continues to be an area where research can benefit more sustainable weed control practices, especially for resistance and invasive weeds. Efficacy of organic products will also benefit the farmers as they select efficient and cost-effective products. Tillage and plant and animal rotations are of special interest.
- Managing disease and pest problems is of high importance. In addition to general research on specific insect controls, continued efforts in breeding crops specific for organic production and management of these issues will increase productivity and economic viability of organic producers.
- Researching challenges involved with animal agriculture in the Western region. The Western region is a major producer of milk products and organic livestock and poultry. To increase the availability of these products to the market place, significant increases in research and extension efforts need to be provided for all aspects of animal production, especially information for rotational and grass fed animals.

References

NOAA National Centers for Environmental Information, 2016. *State of the Climate: Global Analysis for December 2015,* published online January 2016, retrieved on February 3, 2016 from *http://www.ncdc.noaa.gov/sotc/global/201512*.

Svoboda, M. 2016. *U.S. Drought Monitor*. The National Drought Mitigation Center, Lincoln, NE, Retrievedon Feb. 3, 2016 from *http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CAhttp://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA*.

http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA.

USDA. 2014. 2014 *Organic Survey*. USDA National Agricultural Statistics Service (NASS). Washington, D.C.

Appendix B: Northeast Region

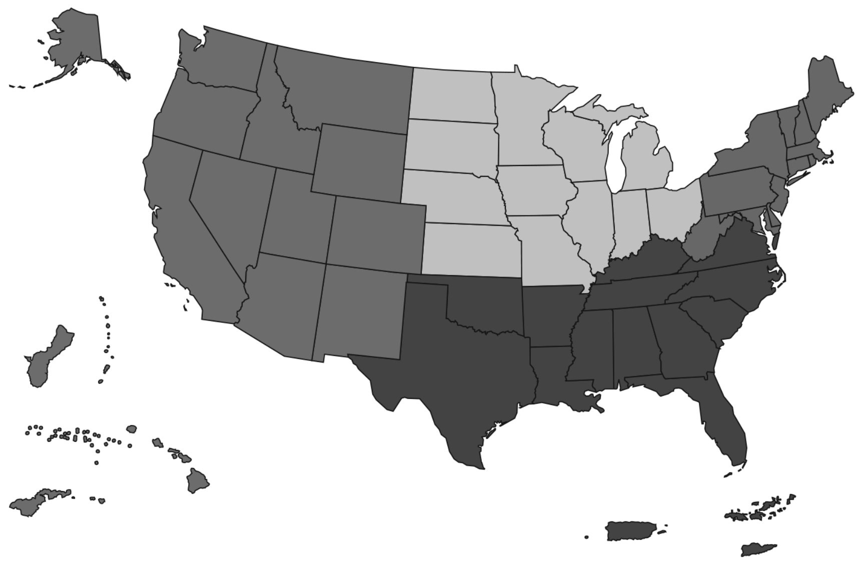
Recommendations for Future Research in the Northeast Region

- Increased research on different tillage techniques and the impact on soil health and weed control.
- Increased research on the soil health and fertility impacts of integrating animals with field crops.
- Increased research on cover crops (different varieties) for erosion control and fertility management.
- Increased research on the nutritional benefits of organic food.
- Increased research on pollinator health and providing native pollinator habitat.
- Increased research on managing weed, disease, and animal health challenges during wet years.

Respondent Characteristics

The Northeast region includes Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Washington, D.C., and West Virginia (see green region on map; *Figure B.1*).

Figure B.1.



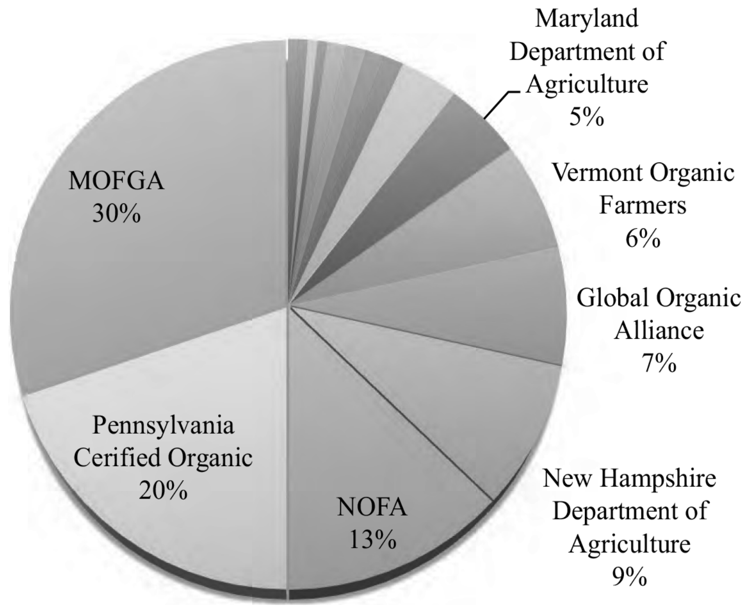
Northeast region in green (SARE, 2016).

The Organic Farming Research Foundation (OFRF) distributed a nationwide survey to organic farmers asking about their research needs. One hundred and thirty-six complete responses came from the Northeastern region, and there were also 60 partially completed surveys that were used in this analysis. Northeast region survey participants are farmers with diverse production systems, farming backgrounds, educations, ages, and income levels.

Organic Farming

Ninety-eight percent of respondents had certified organic acres, and 14.4% of respondents had mixed farms with both organic and conventional production. Thirty-seven percent of northeastern farmers transitioned to organic farming from conventional farming practices, and 60.4% began farming using organic practices. Of the certified farmers in the Northeast, the most common certifiers in order are Maine Organic Farmers and Gardeners Association (MOFGA), Pennsylvania Certifies Organic (PCO), NOFA New York and NOFA Vermont, New Hampshire Department of Agriculture, and Global Organic Alliance (*Figure B.2*).

Figure B.2.

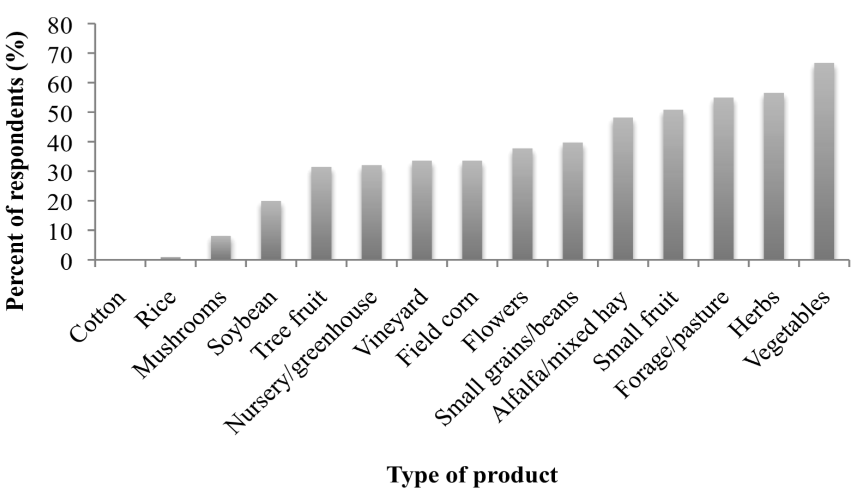


Certifying agencies for the northeastern farmer survey participants (N = 196).

Type of Farm Products

Northeastern farmer survey participants grew a wide range of crops. The most common type of crop produced was vegetables, with 67% of respondents growing vegetables (*Figure B.3*). In addition to the crops listed in *Figure B.3,* Northeast region farmers reported growing nuts, gourds, maple trees and syrup, seeds, garlic and ginger.

Figure B.3.

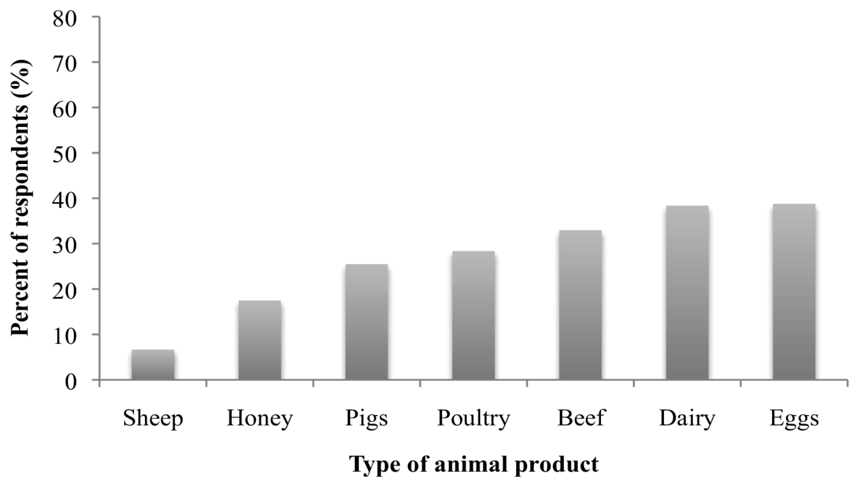


Plant based products produced by surveyed farmers in the Northeast.

Type of Animal Products

75.8% of respondents produced animal products. The most common animal product produced was eggs, but the surveyed respondents produced many different animal products including dairy, beef, and poultry (*Figure B.4*).

Figure B.4.

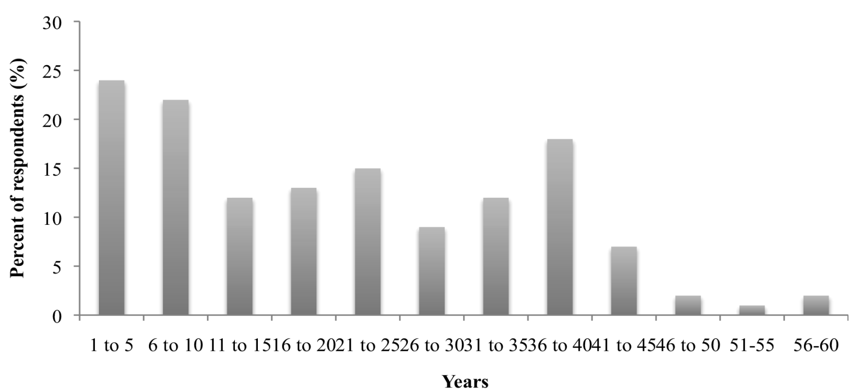


Animal products produced by surveyed farmers in the Northeastern region.

Farming Experience

Surveyed farmers have been farming from 1 to 60 years, with the largest percent (17.6%) farming for 1–5 years and the fewest number of farmers having farmed for more than 45 years (*Figure B.5*). Many farmers started farming organically, yet the majority (54.7%) report transitioning to organic.

Figure B.5.



Number of years survey respondents reported farming.

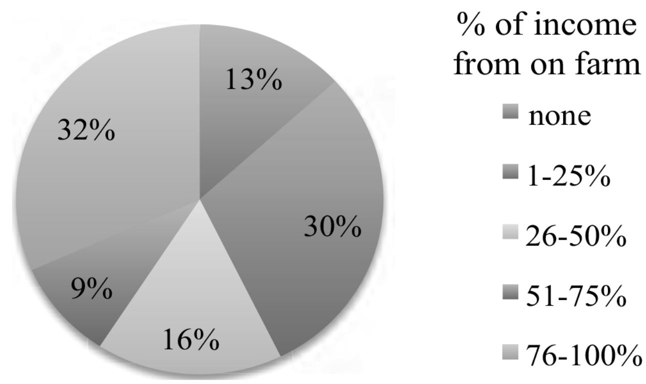
Demographic Information

Of the Northeastern respondents, 68.2% were male and 31.8% were female. Participating farmers ranged in age from 23 to 79. The average age of northeastern farmers in the survey was 53.7 years (N = 150). It was most common for the respondents to have completed a 4 year educational degree (37%), yet many participants also had master's degrees (18%). 13% of participants did not go on to pursue higher education after college, and 14% completed some college.

Farm Economics

Northeastern farmers who took the survey vary in the size, value, and income coming from their farming operations. It was most common for respondents to rely on farm production for 76–100% of their net income, yet other farmers had diversified incomes and jobs other than farming (*Figure B.6*). Half of the farmer participants had farms where a household member worked off-farm for more than 20 hours a week.

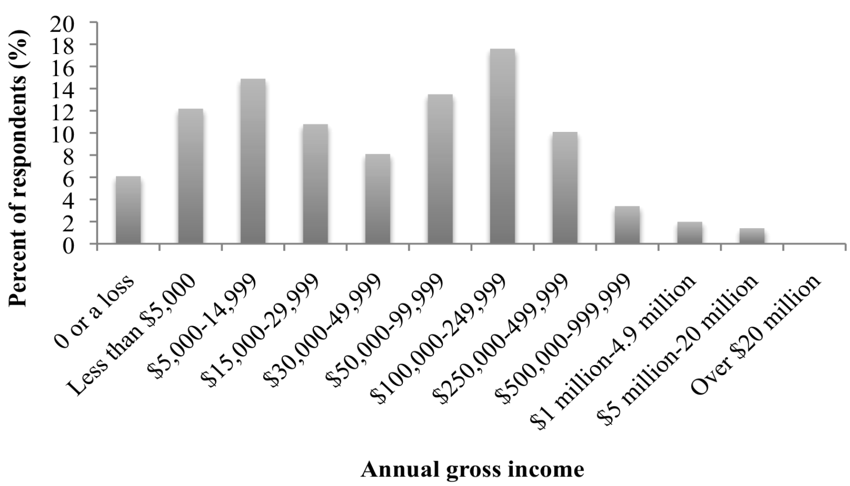
Figure B.6.



Percent of income from farm production.

Gross income from farming ranged from no income or a loss, to over $5M for northeastern survey respondents. It was most common for respondents to earn between $100,000 and $249,999, yet there was great variability in income (*Figure B.7*).

Figure B.7.

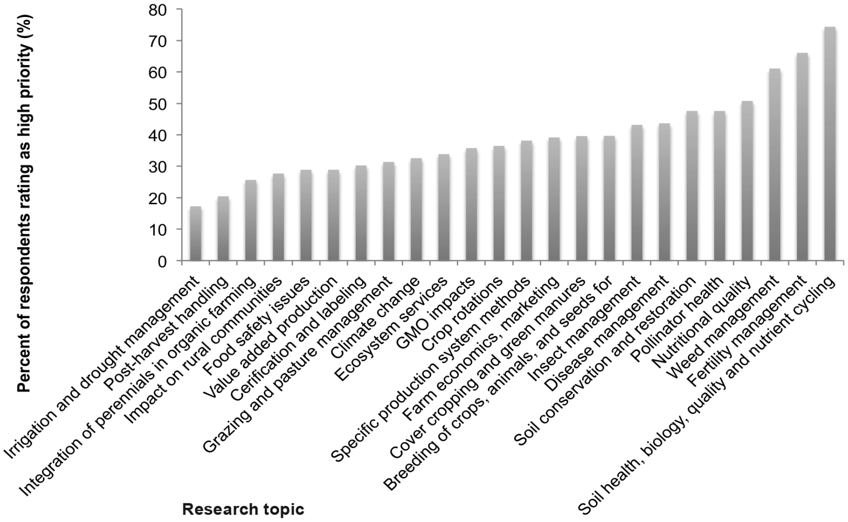


Annual gross income for survey respondents in the Northeast regions.

Top Research Priorities

For the Northeast region, the highest priority identified for research was soil health, quality, and nutrient management, which was rated as a high priority by 74.4% of respondents. The top ten research priorities in order of importance include: (1) soil health, quality, and nutrient management; (2) fertility management; (3) weed management; (4) nutritional quality and health benefits of organic food[;] (5) pollinator health; (6) soil conservation and restoration; (7) disease management; (8) insect management; (9) breeding crops and animals; and (10) cover cropping and green manure (*Figure B.8*).

Figure B.8.



Research priorities of surveyed farmers in the Northeastern region.

Northeastern growers were asked to list their top production challenge. Several themes emerged including: weed management, coping with variable weather, lack of time, economic pressures, aging, soil health, balancing cover crops with economics, finding enough forage, sourcing labor, large pests (groundhogs and deer), and livestock health. One farmer stated that their most pressing challenges are, "labor, cost of labor, and not being able to pay farm crew fair/livable wages that they deserve for the physically demanding work." A common theme in the responses was the challenge of weed and pest control. One farmer explained their challenges as the "accumulation of weeds, insects and disease. Each year I have more volume of each and more variety of each. These three issues make farming more difficult each year." The economic challenges of being a small organic farmer were expressed by many farmers. One farmer stated their challenge is "balancing monetary needs with soil health needs. I should have half of my organic land in cover crop right now but financially I can't afford it, I need land to be in crop production to pay all of my overhead and labor costs." Another farmer expressed the pressure wielded by the structure of the food system, and stated that the "biggest threat we face is the gobbling up of smaller producers by big producers. Pressures of regulation, created by the pressure of large food corporations on legislators, cripple smaller producers."

Soil Health, Biology and Quality

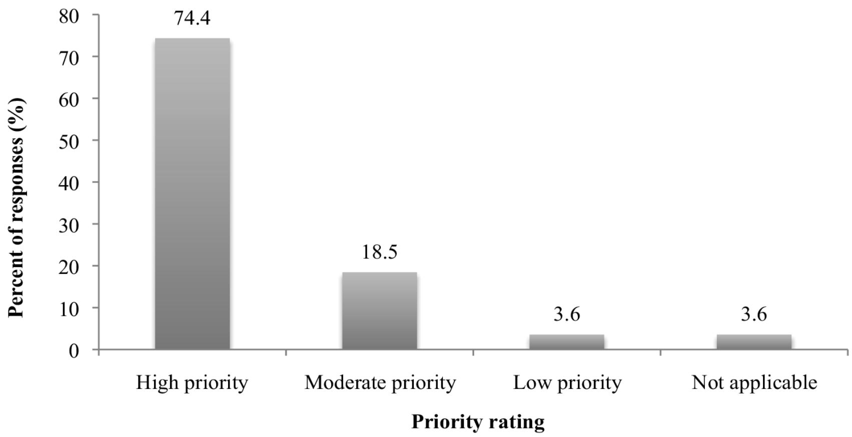
Of the farmers surveyed in the Northeast, 74.4% rated soil health, biology, and quality as a high priority for organic farming research, making it the most commonly rated high priority research topic (*Figure B.9*). 18.5% of respondents rated it as a moderate priority, showing that it is a major priority for the vast majority of farmers in the survey. In an open-ended question on soil health research needs, many farmers commented on the specific needs of their farms. One farmer stated the need for "more accessible information on proper soil management and what is being done in our region would be helpful. A stronger network of farmers and shared information on best practices."

Common comments include a need for more research on:

- The interaction between soil health and weed management.
- Nutrient cycling details as it relates to specific crop rotation patterns.
- Using livestock and grazing as a way to increase soil, livestock and human health.
- How best to manage and balance nutrients when using compost, cover crops, and a very diverse rotation.
- Keeping healthy soils through minimized tillage.
- Developing beneficial soil microbes and mycorrhizae.

- Soil building and nutrient management.
- The effect of compost, cover crops, and diverse rotations on soil health.
- How organic farming can contribute to carbon sequestration.
- Soil health and nutrient cycling related to weed control, livestock forage and hay production.

Figure B.9.



Priority rating of soil health research.

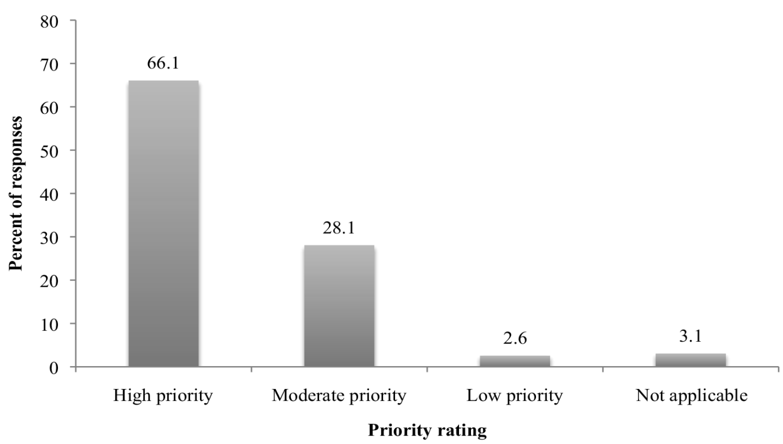
Fertility Management

The majority of respondents rated fertility management as a high priority (66.1%), with many rating it as a moderate priority (28.1%) (*Figure B.10*). One farmer stated, "I'm interested in how fertility connects with weed, pest, and disease management and whether it's possible to build fertility to grow disease and pest resistant crops. Also, how fertility management relates to weed pressure."

Specific research needs stated by farmers in the Northeast region include:

- How the soil fertility balance relates to weed growth, specifically wild mustard.
- Apple and chestnut fertility needs.
- Soil building and fertility improvements for increased yields and carrying capacity.

Figure B.10.



Priority rating of fertility management research.

Weed Management

Over 60% of Northeastern growers listed weed management as a high priority, and many commented that weeds are a major challenge (*Figure B.12*). One grower stated, "Weeds are the number one problem to being a successful organic grower." Respondents were commonly interested in research on the following topics:

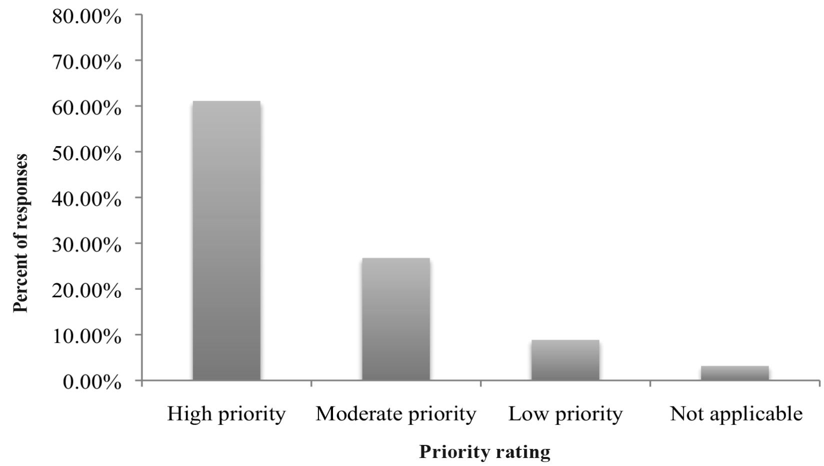
- No-till weed control.
- Organically approved herbicides.
- Rotations for weed control.
- How to prevent weeds from overtaking early stage corn.
- How fertility connects with weed management.
- Effective and economic weed control.
- Weed management techniques during wet years.
- Weed management in orchards.

Farmers also reported specific weeds being challenging in the Northeast region, including: Canada thistle (*Cirsium arvense*), jimson weed (*Datura stramonium*) (*Figure B.11*), annual grasses and field bindweed (*Convolvulus arvensis*).

Figure B.11.

Jimson weed (*Durata stramonium;* Photo by Betty Marose, University of Maryland Extension, 2016).

Figure B.12.



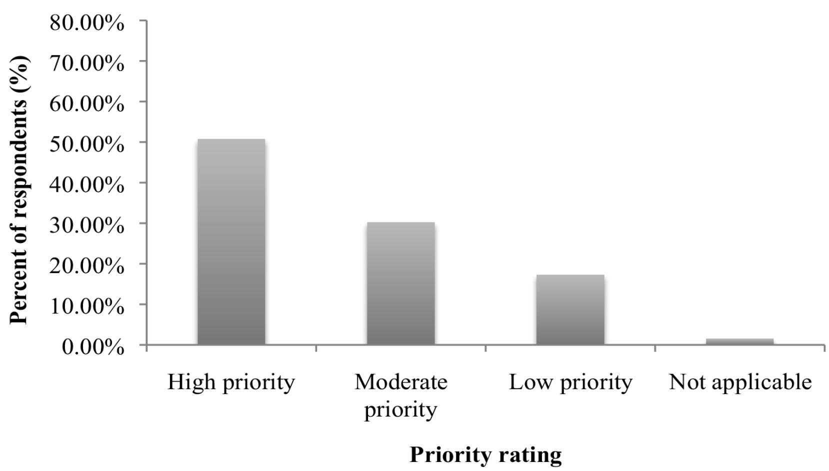
Priority rating of weed management research.

Nutritional Quality of Organic Food

The majority of Northeastern region respondents rated nutritional quality, health benefits, and integrity of organic food as a high priority (*Figure B.13*). One farmer stated, "Consumers are largely unwilling to pay the appropriate prices for certified organic produce that reflect the higher costs of production." To increase consumer knowledge and demand for organic food, farmers expressed interested in the following research topics:

- Distinguishing nutritional variance between new and heirloom varieties.
- How consumers view organic and non-GMO. How consumers see the relationship between the two and what farmers can do with labeling to get them to look for organic.
- Meeting animal welfare guidelines.
- Vitality and storage quality comparisons between conventional, organic and biodynamic food.
- Scientific findings on the value of organic food over conventional.

Figure B.13.

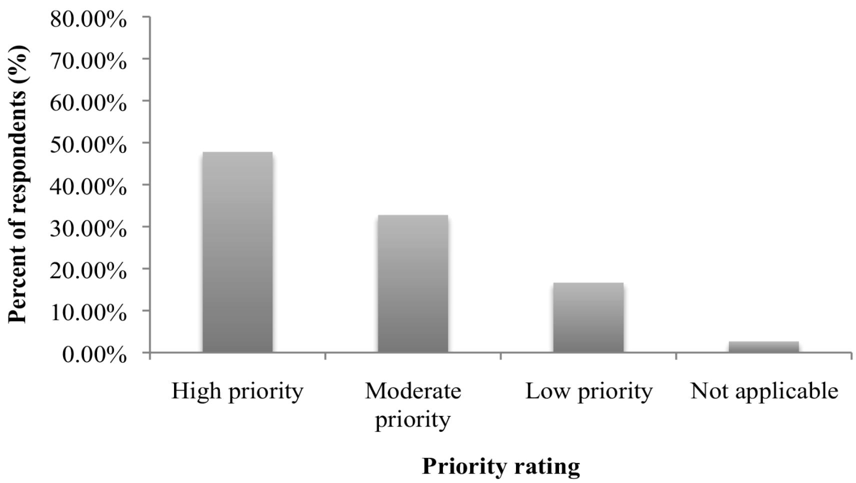


Priority rating of nutritional quality of organic food research.

Pollinator Health

Pollinator health was rated as a high priority for 48% of Northeastern respondents (*Figure B.14*). With bee health a major topic of environmental concern, it is expected that farmers who rely on pollinators for the success of their crops desire research on how to improve pollinator health. Northeastern farmers expressed the need for more research on wild pollinator mortality in greenhouses and which native plant species are best for aiding pollinators. Northeastern farmers also noted the need for organic open-pollinated crop seeds and seeds for organic, native flowering plants.

Figure B.14.



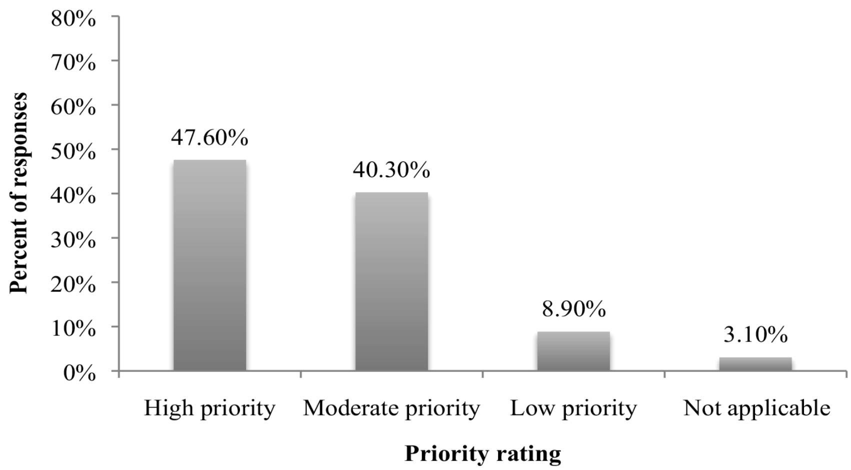
Priority rating of pollinator health research.

Soil Conservation and Restoration

Most respondents rated soil conservation and restoration as an important area of organic research. Forty-eight percent of respondents rated this topic a high priority (*Figure B.15*). Particular issues of interest include:

- Using perennial crops/pasture and no-till for soil health and conservation.
- Erosion prevention.
- Managing cover crops for soil conservation.

Figure B.15.



Priority rating of soil conservation and restoration research.

Disease Management

Plant diseases were reported as a production challenge in the open-ended portion of the survey. Farmers listed the following as topics of interest: soil diseases in high tunnels, potato late blight, livestock diseases, and the need for an effective fungicide other than copper.

Insect Management

Insect management is an important challenge for northeastern growers. Several survey respondents reported managing flies and parasites in cattle as a major obstacle. One farmer stated the need for a computer application to be used in the field for pest and disease identification. Insect pests reported in the survey include mushroom flies, swede midge (*Contarinia nasturtii*), leek moth (*Acrolepiopsis assectella* Zeller), cucumber beetles, squash bugs, spotted wing drosophila (*Drosophila suzukii*), and potato leafhopper (*Empoasca fabae*).

Breeding of Crops, Animals, and Seeds for Organic Production

Over 70% of respondents listed breeding of crops, animals, or seeds as a moderate or high priority. Only 39.7% of respondents listed breeding as a high priority, demonstrating that issues related to soil are more widely applicable and of interest to the northeastern farmers.

Farmers were asked to comment on their specific needs related to breeding. Open-ended responses to the question included the need for fruit varieties with disease and insect resistance, like scab resistant apple, alternative crops suited for the Northeast temperature zone, and developing nitrogen fixing green manures.

Animal Agriculture

With 75% of the surveyed farmers producing animal products like eggs and dairy, many farmers desired research on animal health topics. Farmers expressed interest in research that would lead to better fly and parasite control for livestock. In addition, some farmers expressed their success with dealing with animal production challenges. For example, one northeastern farmer noted that during a wet year they limited the hours of time dairy cows spent on pasture and increased the time spent resting in the barn with plenty of shade and water. As a result, the cows had lower somatic cell counts and had almost no hoof problems.

Conclusions and Recommendations

Surveyed farmers and listening session participants were asked to describe their most pressing production challenge. Several topics emerged as recurrent challenges experienced by many of the Northeast region producers. These challenges are topics for which future research can be prioritized in this region, and include:

- Managing soil health in conjunction with managing pests, weeds and diseases.
- Managing weeds, especially in times of heavy rain.

- Adapting to extreme weather conditions.
- Controlling parasites in livestock.

In addition, recommendations for additional research based on listening sessions in the Northeast, especially the meeting held at the Organic Trade Association Organic Center in Washington, D.C., include:

- Control practices for wireworm and nematodes.
- Marketing/consumer education about organic agriculture as a GMO free production system.
- Weed control/use of perennial crops to reduce weed pressure.
- Economic research on organic production systems.
- Alfalfa as a rotational crop and the impact of GM alfalfa on organic production.
- Technology for the field knowledge, funding, technology.

Appendix C: North Central Region

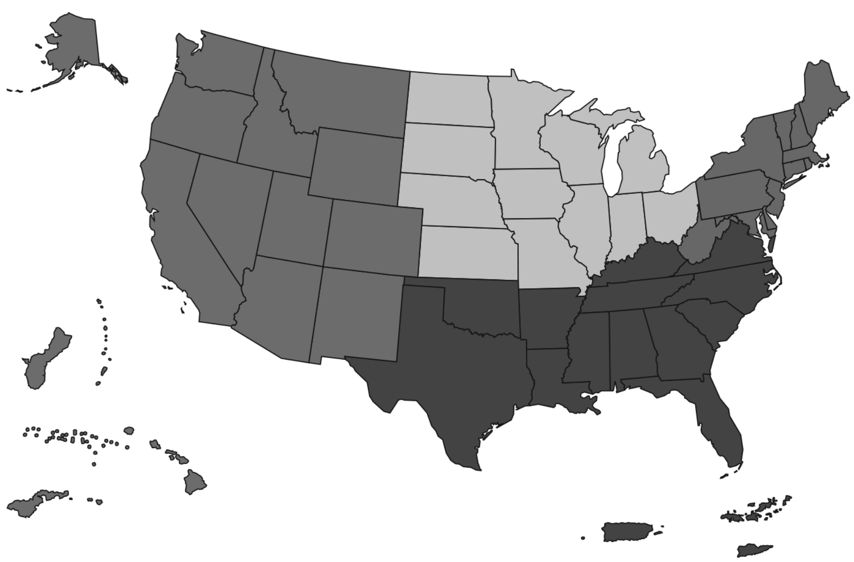
Research, Education, and Policy Recommendations in the North Central Region

- Increased research on livestock health.
- Increased research on GMO contamination and prevention.
- Increased research on soil health practices.

Respondent Characteristics

The North Central Region encompasses 12 states: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin (see yellow states in *Figure C.1*).

Figure C.1.



North Central region in yellow (SARE, 2016).

This regional report is based on 253 complete responses and 68 partially completed surveys from the North Central region.

North Central survey participants are farmers with diverse production systems, farming backgrounds, educations, ages, and income levels.

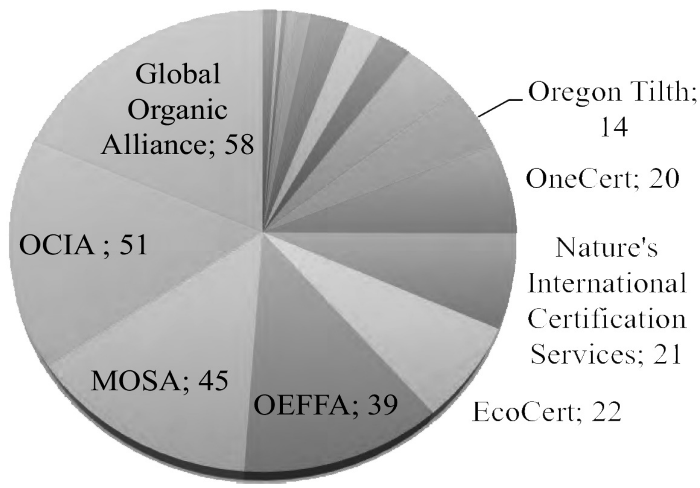
Farmers in the North Central region had been farming from a range of 1 to 51 years.

Organic Farming

The size of the farms in the survey ranged from 0.25 acres to over 5,000 acres. Fifty five percent of farmers in the North Central region transitioned to organic farming from conventional farming practices, and 37% began farming using organic practices. Seventy-seven percent of respondents only farmed organically, and 23%

had mixed organic and conventional production. Some farmers began farming organically as a gardening project, or bought land already certified organic, and several farmers had land taken out of a conservation reserve program (CRP). Of the certified farmers in the North Central region, the most common certifiers in order are Global Organic Alliance, OCIA, MOSA, and OEFFA (*Figure C.2*). Because the survey was conducted online, the opinions of the Amish organic dairy farms in the North Central region are not part of this analysis.

Figure C.2.

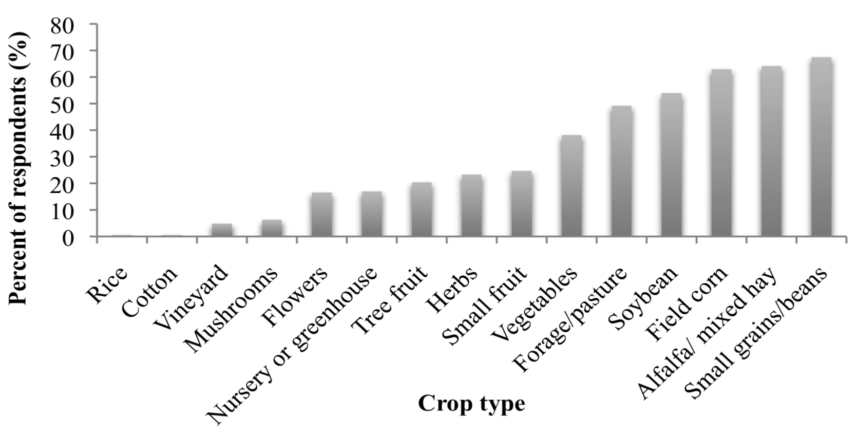


Top organic certifiers for North Central operations.

Type of Farm Products

North Central farmer survey participants grow a variety of crop and animal products, however production is concentrated on grain, pasture, and livestock. The most common type of crop produced was small grains and beans with 67.5% (*Figure C.3*). Other common crops grown include alfalfa, field corn, soybean, and forage and pasture. The dominance of these crops distinguishes this region from other regions that grow predominantly fruit and vegetables. The production of corn, soy, and alfalfa crops in the North Central regions puts these growers at increased risk of GMOs, and the survey found that these farmers are more concerned with GMO contamination than farmers from other regions.

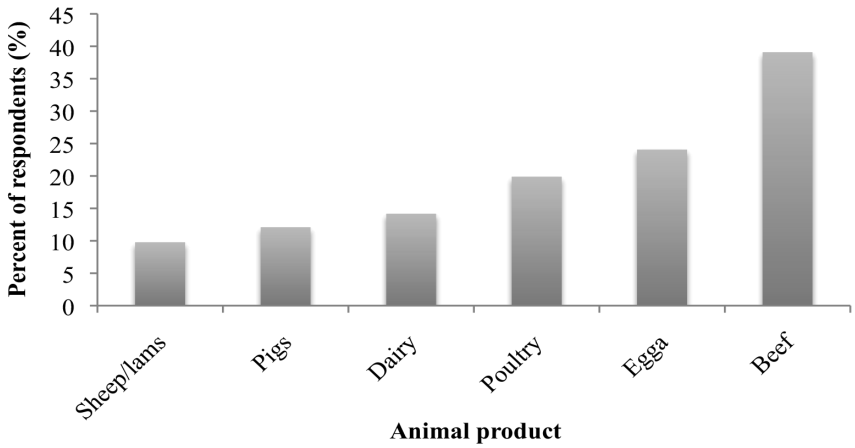
Figure C.3.



Crops grown by North Central operations.

Of the surveyed farmers, 61% produced animal products. Out of the farmers that do produce animal products, the most common product was beef, followed by eggs and poultry (*Figure C.4*). The survey identified research questions and needs specific to animal production. One north central participant stated, "Organic livestock nutrition and health practices are important research areas for us, especially identifying and testing effective allowable treatments for when animals are sick (pneumonia, scours and other intestinal problems, milk fever, pinkeye, *etc.*). It's fine to say organic farmers should use systems that keep animals healthy, but they do get sick and you want to know how to be able to help them right away."

Figure C.4.

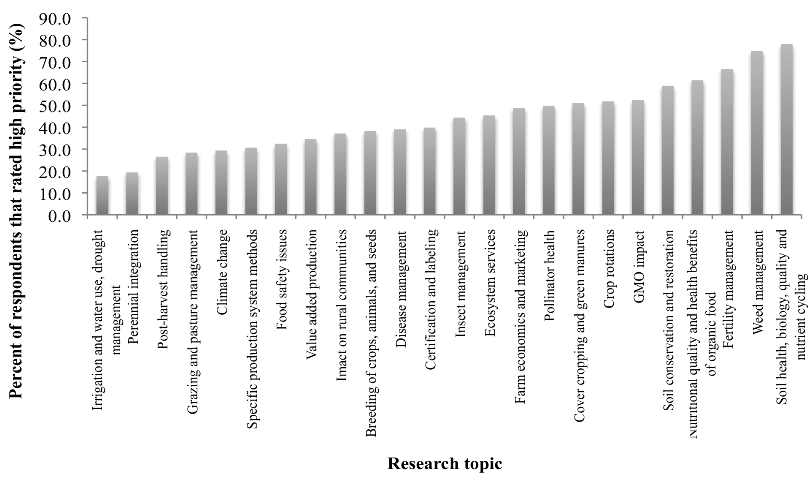


Animal production by North Central producers.

Top Research Priorities in the North Central Region

Farmers in the North Central region marked many research topics as high priority (*Figure C.5*). The top five priorities in order of highest number of respondents rating it a high priority are: (1) soil health, biology, and nutrient cycling, (2) weed management, (3) fertility management, (4) nutritional quality and health benefits of organic food, (5) soil conservation. The impact of GMOs, crop rotation, cover cropping, and pollinator health were also all marked as high priorities by 50% or more of the respondents.

Figure C.5.



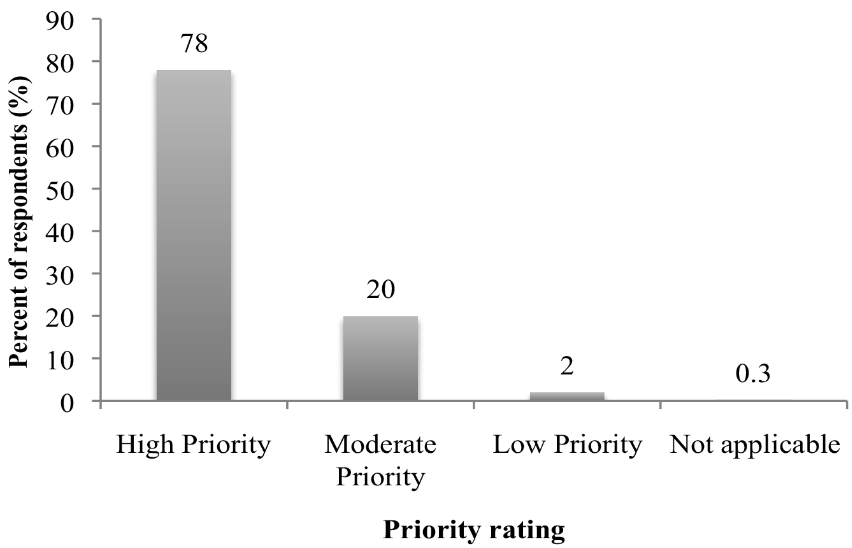
Top research priorities listed by North Central producers.

Soil Health, Biology, and Nutrient Cycling

Research on soil health was identified as a high priority by 78% of respondents in the North Central region (*Figure C.6*). Main areas for which farmers requested research were tillage and reduced tillage and soil health, cover crops and soil health, and crop rotations and soil health. Farmers expressed the need for research to answer questions such as:

- "How can cover crops be used to provide fertility requirements in perennial systems where tillage is not used?"
- "How does active soil biology relate to lessening of erosion?"
- "What is the impact of various methods of tillage on soils?"
- "How can I find products and sources I can trust to build my soils at affordable costs?"
- "How does livestock manure affect soil biology?"
- "What are practices to improve soil carbon/ increase soil organic matter, water holding capacity, and biology?"

Figure C.6.



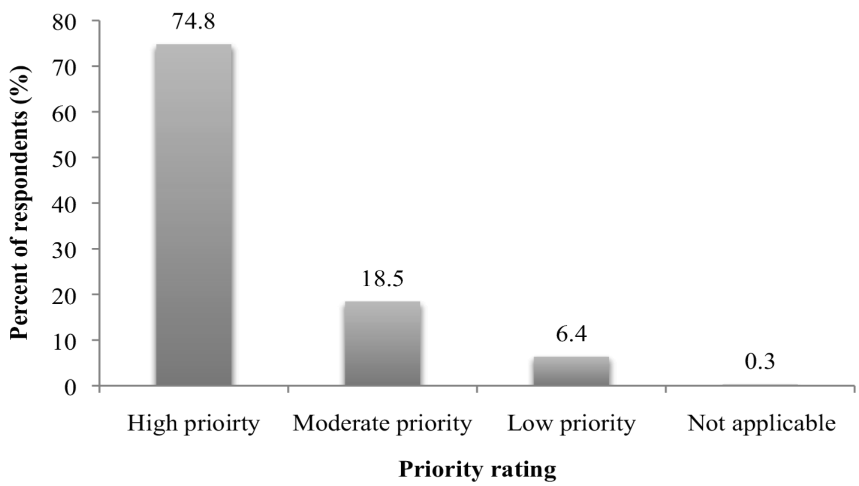
Priority rating of soil health among farmer respondents.

Weed Management

Weed research is a high priority for 75% of North Central farmer respondents (*Figure C.7*). North Central farmers identified several problematic weeds in the region, including purslane (*Portulaca oleracea*), bindweed (*Convolvulus arvensis*), and giant ragweed (*Ambrosia trifida*). There was substantial interest in the role crop and livestock rotation management could play into weed control. Farmer comments on specific needs include:

- "Using animals to manage weeds, disease and pests. The effect animals might have on these types of management."
- "Rotation strategies to decrease annual weed pressure."
- "Rotation/tillage strategies or organic approved materials to eliminate bind weed."
- "Using weeds to our benefit—what do they put back into the soil if tilled in?"

Figure C.7.

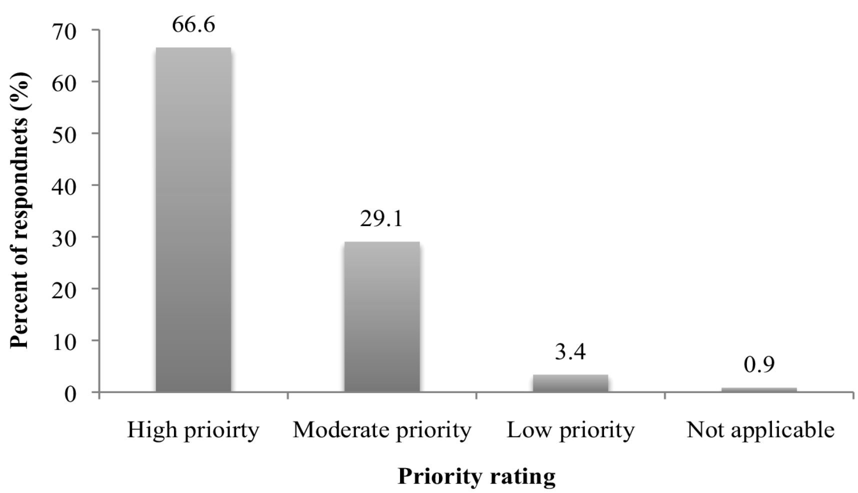


Priority rating for weed management.

Fertility Management

Fertility management, as part of the larger topic of soil health, was rated as a high priority by 66.6% of respondents (*Figure C.8*). Survey respondents particularly highlighted the need for research related to fertility management and soil conservation and crop rotations.

Figure C.8.



Priority rating for fertility management.

The respondents listed the following as specific topics of interest:

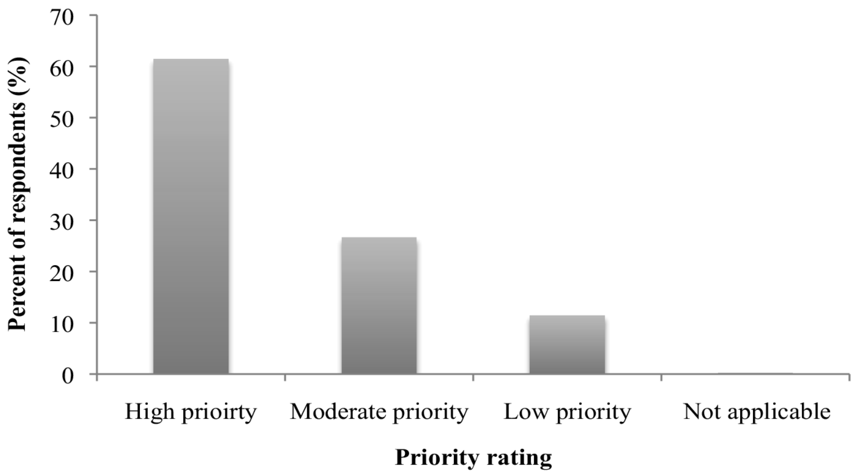
- Soil fertility balance and natural nitrogen, phosphorous, and potassium sourcing.
- Need research on cost effective ways to maintain or improve soil health and fertility when farmed organically particularly when there is no access to organically improved inputs within a reasonable distance.
- Fertility based on microbial populations as opposed to inputs.
- There are many inputs for fertility with little research to back it up. Much more could be done with this.

- Building and maintaining soil fertility organically without manure.
- Pasture and forage soil fertility topics to support organic dairy and grassfed systems.

Nutritional Quality and Health Benefits of Organic Food

Sixty-two percent of respondents rated nutritional quality and health benefits of organic food as a high priority (*Figure C.9*).

Figure C.9.



Priority rating for nutritional quality and benefits of organic food.

North Central farmers stated they were interested in the:

- "Impact of pesticides: drift, health impacts to farmers, consumers, wildlife and livestock."
- "Nutritional information of organic *versus* conventional food."
- "Consumer perspective on food health and safety."

Impact of GMOs

Research on the impact of GMOs on organic farming was rated as a high priority by 52% of North Central farmer respondents. GMO research is of greater interest to North Central growers than for growers in other regions. One farmer stated, "Organic crop markets are very strong at this time. The issue for me is that I would like to see some sort of common sense policy within USDA that would address the issue of GMO contamination given that I was not able to sell all my entire corn crop into the food grade market this past spring, (2014 crop), due to GMO contamination from my neighbor's farm. It appears that people within USDA consider our loss to be a loss in our premium only. They do not realize that typically the potential of receiving a premium comes at a cost, such as growing specific varieties that yield a little less, more time and money dedicated to weed control, *etc.*" Six percent of farmers (15 farmers) in the region reported having a shipment of product rejected due to GMO contamination. Farmers in the survey report:

- Feeling "uneasiness and concern."
- "Losing production due to sizable buffer strips."
- "We have to plant later to prevent cross pollination. This really hurt us."
- "All my neighbors plant GMO and I am always concerned with cross pollination."
- "We need more published research on the effects and differences of GMO *vs.* non GMO crops. Also for pollinator health!!"

Cover Crops

Of the North Central farmers surveyed, 47.3% reported regularly using cover crops, demonstrating that this is an important fertility management strategy. Many farmers (51%) reported that research on cover crops is a high priority. One farmer stated the need for “optimal practices in terms of cover crop incorporation (timing and tillage tools).” Another farmer expressed the desire for enhanced educational opportunities on the topic of cover crops, and stated, “I would like to have more discussions, trainings, workshops and specifically **examples.** I would like to visit farms that are doing cover crops and talk to farmers who have tried it.”

Pollinator Health

Research on pollinators was rated as a high priority by 50% of North Central farmer respondents. One farmer respondent stated, “Regarding pollinator health, insufficient attention is given to the benefits of legumes that bloom multiple times of year, such as alfalfa and red clover, distributed over multiple farms in a community so that there are always some field in bloom.” Another farmer stated that there needs to be more research on pollinator habitat and conservation.

Insect Pests

Respondents rated research on insect pests as less of a priority than weed management, with only 44% of respondents listing insect research as a high priority. However, farmers did list several topics for which they would like more research. These include:

- Types of insects in our area that are harmful and helpful to row crops.
- Fly and parasite management practices and their impact on non-target insects (dung beetles, pollinators, *etc.*).
- Organic control of diseases and insects in organic fruits in humid eastern U.S.
- Livestock insect management (flies and parasites).

Livestock Research

OFRF held a listening session in La Crosse, Wisconsin at the MOSES Conference in 2015. During this listening session, a group of organic farmer attendees were asked to list their research needs related to livestock management. The needs identified include:

- Veterinary care (costs, preventative practices).
- Impact of grass-based systems on animal disease (long-term study).
- Incidence of lameness on organic farms; causes; nutrition; symptoms; and housing.
- Stockmanship/cattle handling/humane treatment best management practices.
- Breed performance in organic systems (health, pathogens, and parasites).
- Parasite prevention on pastures.
- Poultry breed and ration customization for season/climate, environment.
- Feeds, pasture, and markets.
- Food safety and health implications for outdoor access of poultry.
- Integrated livestock/crop systems (food safety; pest/disease suppression).
- Effective treatment options for poultry diseases and human pathogens.
- Effective alternatives to synthetic methionine.
- More research on probiotics for animal health (efficacy, risks, costs, and benefits).
- Parasite management for hogs and small ruminants.

Conclusions and Recommendations

In the survey, farmers were asked to describe their biggest production challenge. Several topics emerged as recurrent challenges experienced by many of the North Central producers. These challenges are topics for which future research can be prioritized in this region, and include:

- Marketing and profitability.
- Weed management.
- Weather and climate change (excess rain).
- GMO contamination and avoidance.
- Insufficient organic meat processors and USDA meat and poultry inspectors.
- Meeting the Food Safety Modernization Act requirements.

In addition, comments from the listening sessions in the North Central region emphasized the need for additional research on more consumer related research on:

- Food quality as a function of production practices.

- Food waste in organic production chains compared to conventional chains.
- Sociological research on the transition to organic production and data that establishes the economic benefits or organic production.

Appendix D: Southern Region

Summary of Research Recommendations

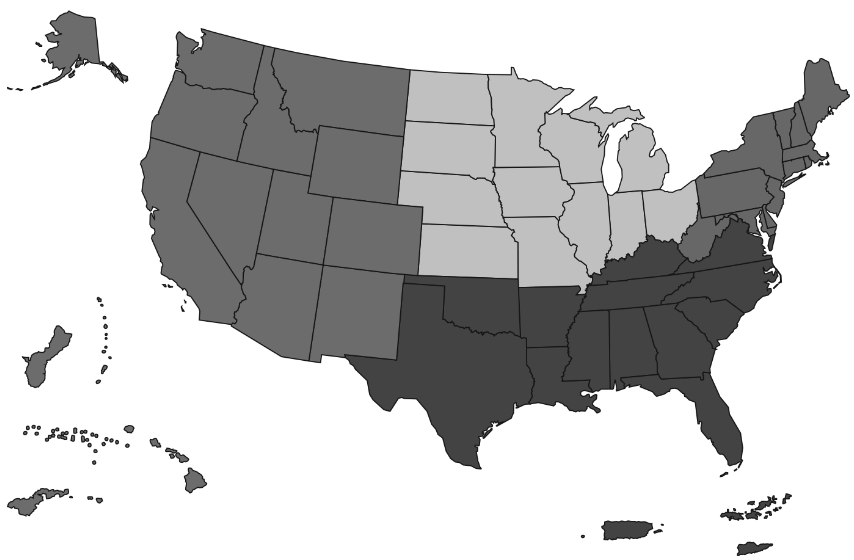
Based on the organic farmer survey detailed below, the Organic Farming Research Foundation recommends research in the Southern region that focuses on top priorities, including:

- Management of fertility and soil health.
- Management of problematic insect pests such as stink bugs.
- Control of weed pests like johnsongrass (*Sorghum halepense*).
- Market opportunities and consumer awareness concerning organic food.

Respondent Characteristics

The Southern region encompasses Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, Puerto Rico and the U.S. Virgin Islands. (See red states in *Figure D.1*).

Figure D.1.



Southern region is shown in red (SARE, 2016).

This regional report is based on 93 complete responses and 46 partially completed surveys, for a total of 139 participants in the Southern region. Southern survey participants are farmers with diverse production systems, farming backgrounds, educations, ages, and income levels. The length of time farmers in the Southern region have been farming ranged from less than 1 year to 56 years.

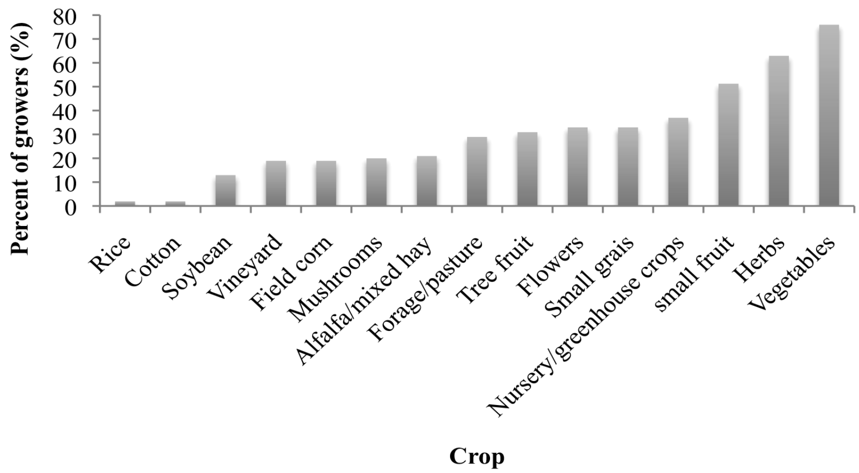
Organic Farming

The size of the farms in the survey ranged from less than 1 acre to over 57,500 acres. Thirty five percent of southern farmers transitioned to organic farming from conventional farming practices, and 58% began farming using organic practices. Seventy-two percent of respondents only farmed organically, and 27% had mixed organic and conventional production.

Type of Farm Products

Southern region survey participants grew many different crops. The most common type of crop produced was vegetable crops with 67.5% (*Figure D.2*). Other common crops grown in this region include: herbs, small fruit, nursery crops, and small grains. In addition to the crops listed in *Figure D.2,* growers in this region grew pecans, tobacco, peanuts, and chia seeds.

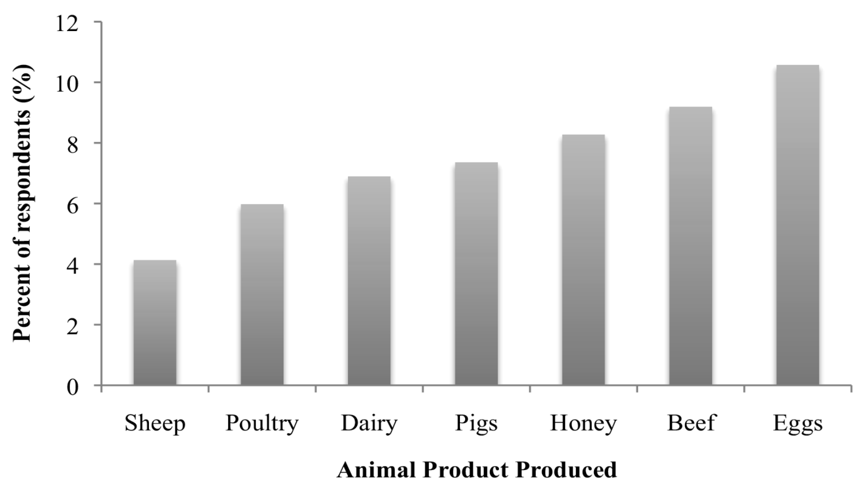
Figure D.2.



Percent of Southern region survey participants growing different crops.

Of the surveyed farmers, 45.8% produced animal products (*Figure D.3*). Out of the farmers that produce animal products, the most common product was eggs, followed by beef and honey. The survey identified research questions and needs specific to animal production in the Southern region. One farmer expressed concern about the Food Safety Modernization Act requirements and another farmer requested research to study using chickens to improve soil health.

Figure D.3.

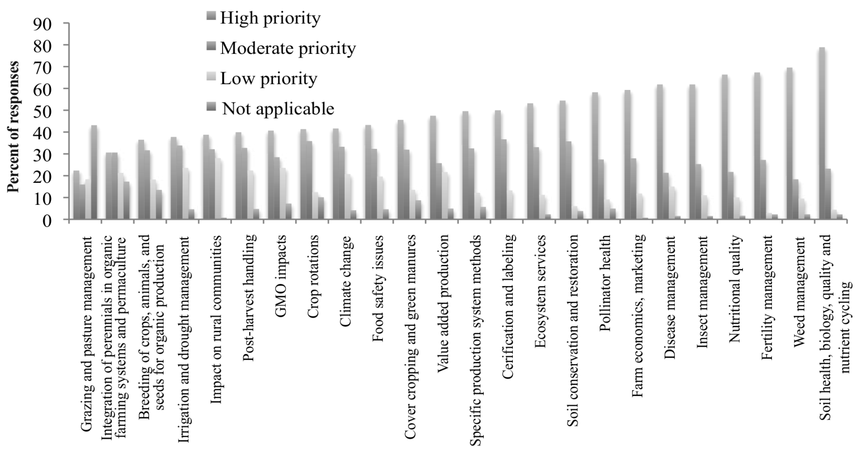


Animal products produced by surveyed farmers in the Southern region.

Top Research Priorities in the Southern Region

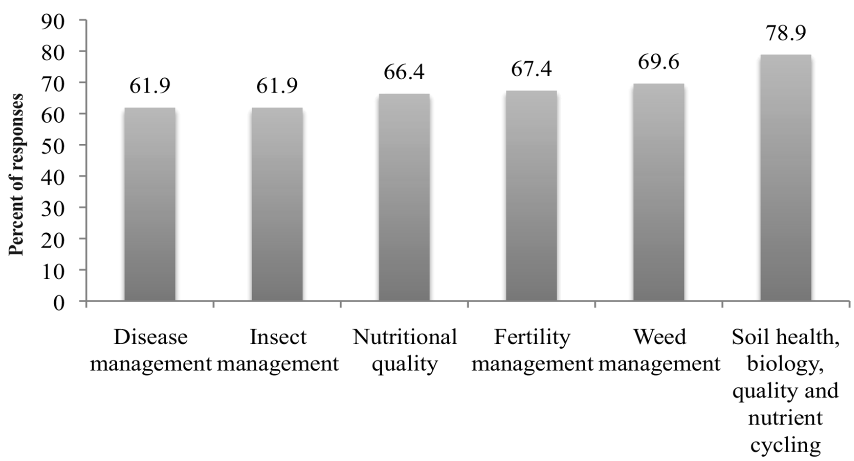
Farmers in the Southern region marked many research topics as high priority (*Figure D.4* and *D.5*). The top five priorities in order of highest number of respondents rating it a high priority are: (1) soil health, biology, and nutrient cycling, (2) weed management, (3) fertility management, (4) nutritional quality and health benefits of organic food, (5) insect management. The impact of GMOs, crop rotation, cover cropping, and pollinator health were also all marked as high priorities by 50% or more of the respondents.

Figure D.4.



Priority ratings for all research topics listed in the survey.

Figure D.5.

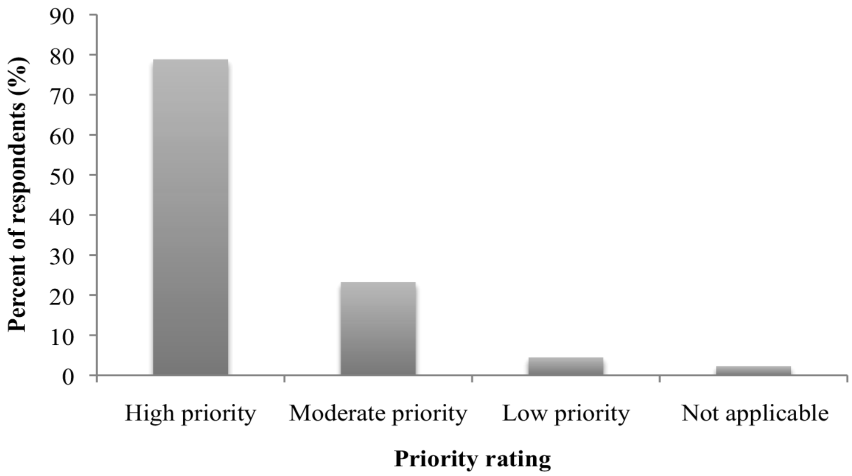


Top six priorities in the Southern region.

Soil Health, Biology, and Nutrient Cycling

Research on soil health was identified as a high priority by 79% of respondents in the Southern region, making it the topic most commonly marked high priority (*Figure D.6*). Main areas for which farmers requested research were no-till organic practices, fertility for pest and disease resistance, identifying the soil bacteria and microbial requirements, cover cropping and green manures for improved soil health, and tillage and reduced tillage practices to build soil fertility. One southern farmer stated, “Soil health is the foundation to the organic method. As a new farmer, the more that I can learn about improving the soil, the better my farm results will be.” Another farmer stated that their goal is, “achieving adequate fertility levels so that crop yields can approach those of conventional farming.” This farmer went on to voice a concern about “the exposure of viruses and bacteria to workers spreading approved manure based soil supplements.”

Figure D.6.



Priority rating of soil health among farmer respondents.

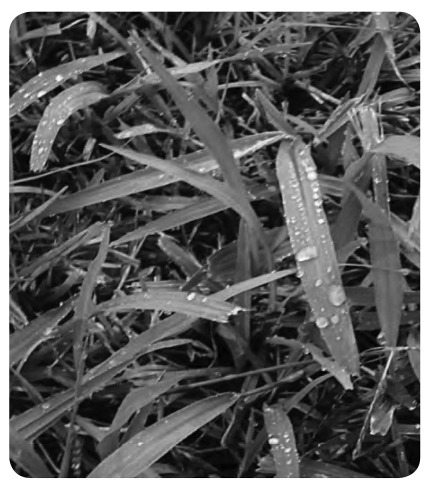
Weed Management

Weed research is a high priority for 69% of southern farmer respondents (*Figure D.9*). Southern farmers identified several problematic weeds in the region, including knotgrass (*Paspalum distichum*), coffee weed, pigweed (*Amaranthus palmeri*) (*Figure D.7*), crab grass (*Digitaria sanguinalis*), johnsongrass (*Sorghum halepense*) (*Figure D.8*). One Southern farmer stated, "Weeds/Pig weed has come out of nowhere to consume my tomato, eggplant, okra and pepper field. We are hand pulling thousands of the weeds from 1′ to 5′ tall."

Figure D.7.

Palmer amaranth pigweed, By Pompilid—Own work, CC BY–SA 3.0, *https://commons.wikimedia.org/w/index.php?curid=20082880*.

Figure D.8.

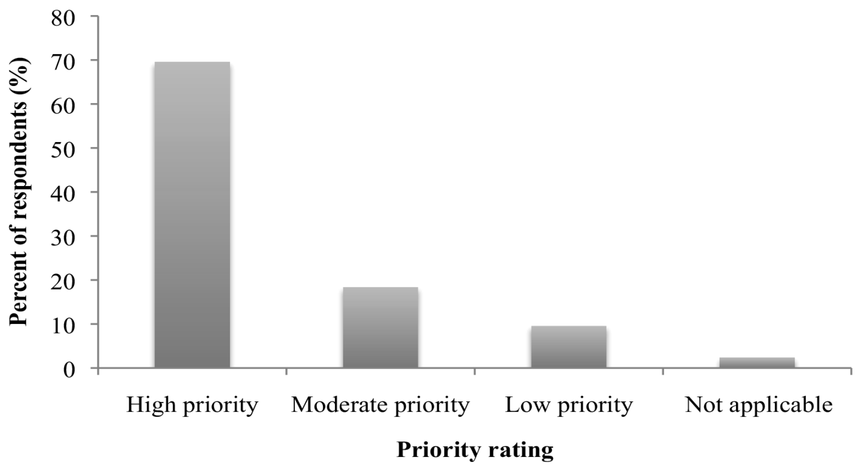


Johnsongrass (public domain).

Another farmer expressed the magnitude of the research need as follows: "Weeds have been the biggest issue through the years. Research into the favored growing conditions of different weeds would be great. If possible, we farmers can create a soil environment which favors crops and hampers weeds by different nutrient levels. Information on the growth cycles of weeds would be helpful in order to delay planting to miss prime weed germination periods." Farmer comments on specific needs include the need for research on:

- Weed control in perennial crops.
- The plant diseases carried by weeds.
- The impacts of climate change on the invasion of weedy, woody vines.
- Controlling weeds in high rainfall and high humidity conditions.

Figure D.9.

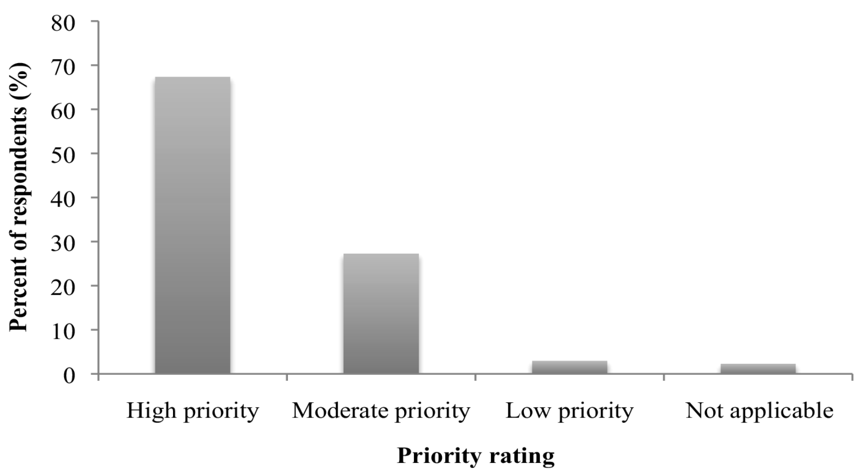


Priority rating for weed management.

Fertility Management

Fertility management, as part of the larger topic of soil health, was rated as a high priority by 67.4% of respondents (*Figure D.10*).

Figure D.10.



Priority rating for fertility management research by Southern survey respondents.

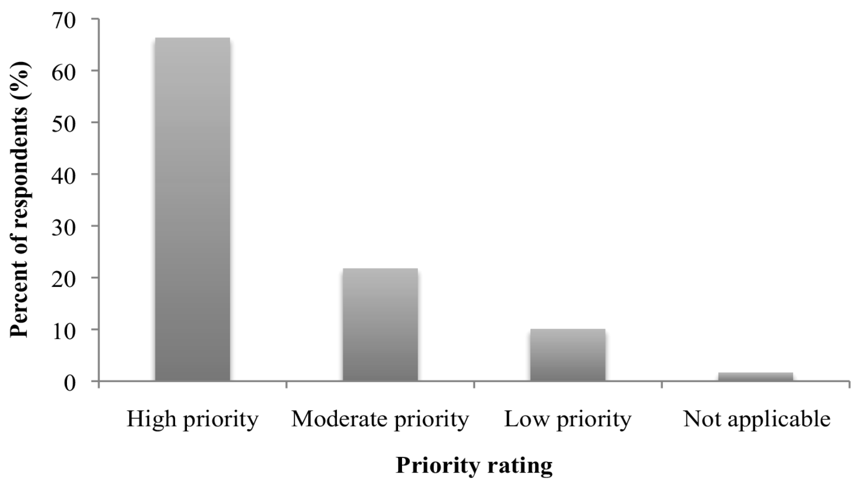
Southern respondents listed the following as specific fertility topics of interest:

- Achieving adequate fertility levels so that crop yields can approach those of conventional farming.
- Optimum fertility not only for production but also for pest and disease resistance.
- Maintaining fertility while reducing soil borne disease and overwintering pests.
- Inputs. One farmer stated, "We need more research on the different fertility inputs. There are many 'snake oil' products out there which cost people money. Some research on the timing of the release of nutrients from different fertility products would help as well."
- Restoring abused land and improving fertility under organic practices.

Nutritional Quality and Health Benefits of Organic Food

Sixty-six percent of respondents rated nutritional quality and health benefits of organic food as a high priority (*Figure D.11*).

Figure D.11.



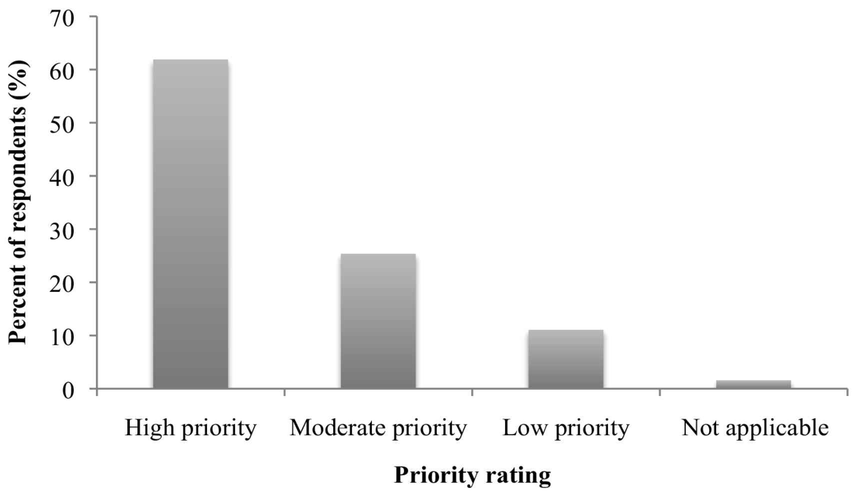
Priority rating for nutritional quality and health benefits of organic food research.

Southern farmers stated they were interested in the views of consumers regarding the integrity of organic certification. For example, one farmer stated, "The organic label has lost its luster among consumers, who prefer 'local' foods now. Organic production has high input costs but cannot command a corresponding price point to remain competitive." Another farmer voiced concerns regarding the health of the nation and convention agriculture's link to cancer. "Educating the public on how much healthier it is to go organic. People need to wake up and understand that this country is overweight, lazy and dying. People want to find a cure for cancer and I strongly believe that the rapid growth in cancer is what we are eating. And the drug makers are getting wealthy on selling a pill for all of our health problems when it could be fixed with food!!!!"

Insect Pests

Research on insect pests was rated as a high priority by 61.9% of Southern respondents (*Figure D.12*).

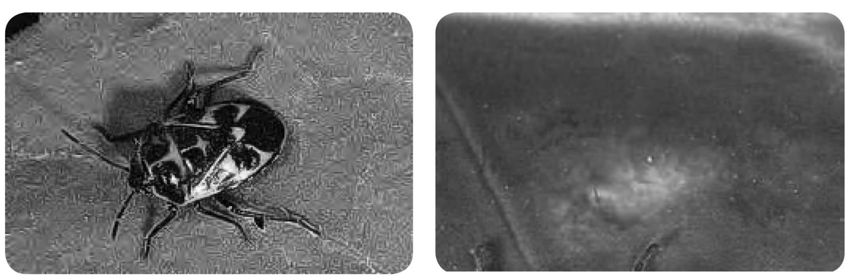
Figure D.12.



Priority rating for insect pest research in the South.

Farmers listed specific pests and the most challenging crops infestations such as: root maggots in garlic, onions and cabbage, worm larva in sweet peppers, and stink bug damage in corn and beans. Main pests listed by growers include stink bugs (including harlequin bugs; *Figure D.13*), spotted wing drosophila (*Drosophila suzukii*), pickleworm (*Diaphania nitidalis*), squash bug (*Anasa tristis*), Japanese beetle (*Popillia japonica*), kudzu bugs (*Megacopta cribraria*), and flea beetle. One farmer described the stink bug problem, "Stinkbugs on all tomatoes, eggplant, and peppers this spring. 100% crop devoured and unsalable." One farmer stated their interest in better understanding of how to use beneficial insects instead of approved substances such as dipel. One farmer also mentioned the need for effective parasite control in beef cattle.

Figure D.13.

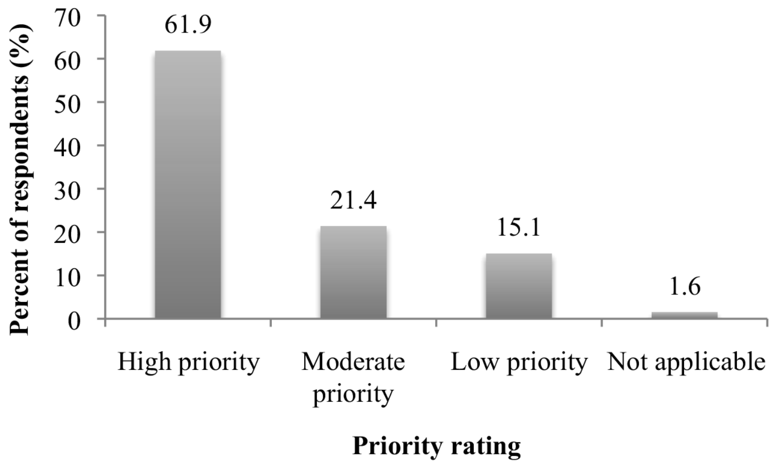


Harlequin bug (left) and plant damage from harlequin feeding (Right) (Source: UC IPM).

Disease Management

Sixty-two percent of Southern region survey respondents rated disease management as a high priority (*Figure D.14*). The wet and humid conditions throughout much of the Southern region create conditions which are conducive to the establishment of crop diseases. One farmer stated, "Humidity and high rainfall of the U.S. Southeast makes vegetable crop production difficult given the resulting disease." Specific diseases of concern include orange cane blotch (*C. vericens*) in blackberry and blueberry, downy mildew in cucurbits, and mildew in grape vines.

Figure D.14.



Priority rating for disease management research among Southern region farmer respondents.

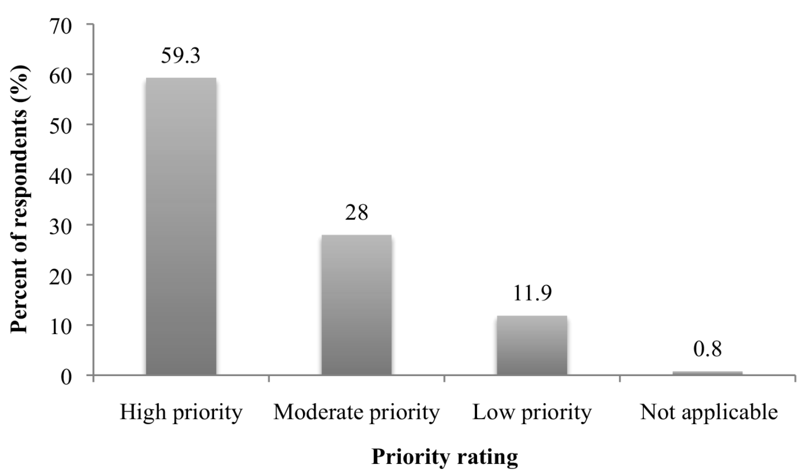
Specific research needs regarding disease management include:

- Maintaining fertility while reducing soil borne disease and overwintering pests.
- Breeding disease resistant cultivars.
- Disease research for organic vegetables in hot, humid, high-rainfall climate.
- Disease control through companion crops and rotation.
- Controlling diseases during wet spells and with climate change.

Farm Economics and Marketing

Many farmers (59%) rated farm economics and marketing research as a high priority (*Figure D.15*). Compared with the other regions, economics, marketing, and consumer behavior is a much higher priority in the South. With the smallest share of organic acres and value in the South, there is a great need to expand the market and strengthen organic production in the region.

Figure D.15.



Priority rating for farm economics and marketing among Southern region farmer respondents.

Some of the specific research priorities in the Southern region include:

- Processing and marketing.
- Balancing production output to match marketing demand. One farmer stated, "Markets are plentiful. Prices are all over the board with different channels. Toughest problem is achieving a steady production volume to fit which volume marketing channel best fits our production from week to week and predicting and marketing to the channel a week or 2 in advance of actual harvest. Crops come in weak, then strong and the channel varies from wholesale to CSA to farmers market depending on the volume from that crop. Prices vary drastically from channel to channel and juggling which call to make is tough."
- Marketing the organic label.
- Transitional crop marketing.
- Optimal marketing practices for small farm sales
- Effective marketing tools geared toward those with limited education and resources. Creating a new model that supports new farmers.
- Food literacy to encourage more southerners to eat fruits and vegetables.

Pollinator Health

Research on pollinators was rated as a high priority by 58% of southern farmer respondents. Farmers in the south emphasized planting more pollinator attractors and building pollinator habitat (*Figure D.16*).

Figure D.16.

European honey bee (*Apis mellifera*).

Conclusions and Recommendations

In the survey, farmers were asked to describe their biggest production issue. Several topics emerged as major challenges for Southern region producers. These challenges are topics for which future research can be prioritized in this region. They include:

- Insect pests, especially stink bugs.
- Weed control, especially johnsongrass (*Sorghum halepense*).
- Lack of accessibility to the commercial market.
- The development of a food safety plan.
- Weather and climate change—heavy rain which is causing weed and disease problems.
- Profitability and consumer education.
- Lack of reliable labor.

In addition, comments from the listening sessions held in the Southern region reinforced the need for research on the areas listed above. In particular, we recommend research and outreach in the Southern region related to access to markets, soil health, and coping with troublesome insects and weeds.

Appendix E: GMO Report

Results from the 2015 National Organic Farmer Survey

Under the National Organic Program, organic agriculture prohibits the use of genetically engineered (GE) crops. Organic farmers must not use GE crops and they also must take steps to avoid contact with GE products in order to prevent cross contamination. Examples of GE avoidance methods by organic farmers include the following:

- Testing seed sources for GE traits.
- Changing the schedule of crop planting to have different flowering times for organic and GE crops.
- Creating agreements with neighbors who plant GE crops.
- Creating buffer zones between neighboring GE crop fields.

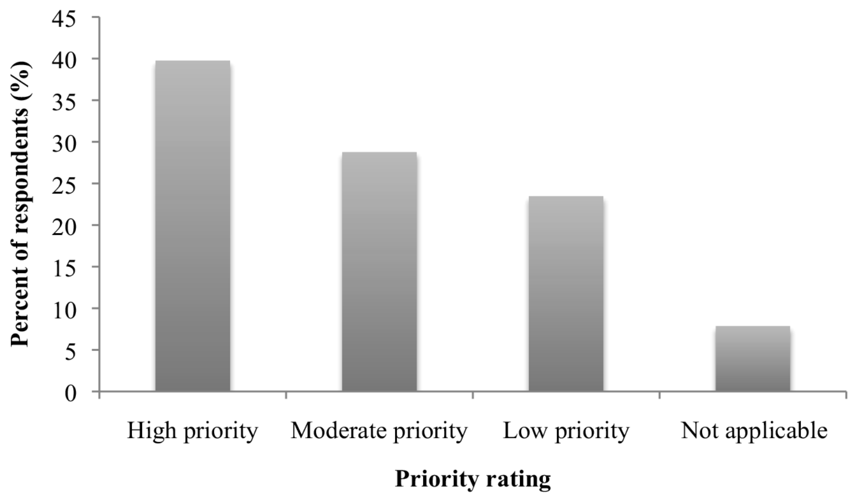
Despite these methods, organic farmers experience unintentional crop contamination with GE traits. For crops like corn and alfalfa, there is a risk that pollen from neighboring GE crop plantings will contaminate the organic crops. Unintentional GE crop contamination is a source of worry for organic producers, who fear having their products rejected if they are found to be contaminated. GMO avoidance practices are costly for organic farmers due to delayed planting and lost production due to taking land out of production for buffer areas.

In 2015, the Organic Farming Research Foundation surveyed organic farmers and asked about their experience with GMO contamination and the impacts on their farms. Nine hundred and nine organic farmers completed the survey and 494 partially completed the survey. This response of 1,403 organic farmers represents approximately 10% of the current population of U.S. organic farmers (USDA, 2015).

Importance of GMO Research

Nationwide, 39.8% of organic farmers rated the impact of GE crops on production, practices, sales, markets, and seed availability as a high research priority (*Figure E.1*). Regions in the Midwest where there are more GE crops grown (like corn and soy) expressed the greatest need for research on GE crop impacts.

Figure E.1.



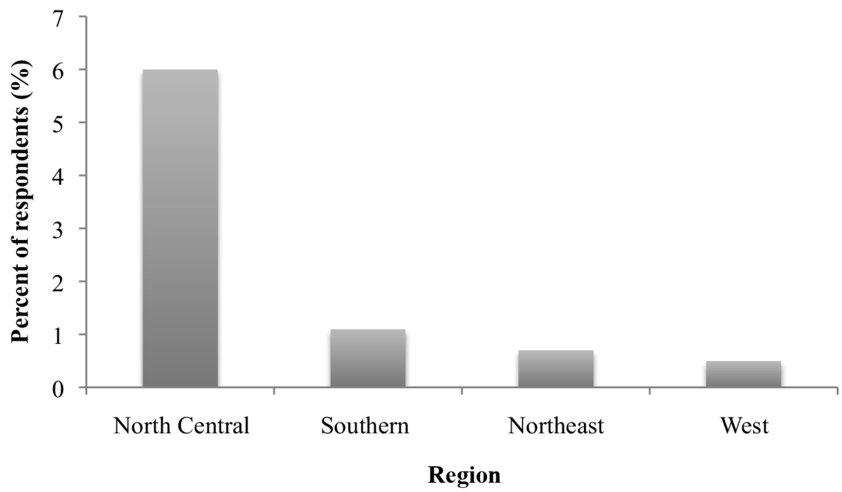
Priority rating of GE crop research among surveyed organic farmers (N = 1,130).

Farmers stated that there is a need for specific types of research and information on GE pollen drift and other contamination issues. In addition, farmers stated that there is a need to communicate with conventional farmers about problems of drift without alienating them. One farmer mentioned that there is an opportunity to find solutions to the problem and conflicts surrounding GE crop contamination by reinforcing the understanding that both small organic farmers and small conventional farmers make important economic and social contributions to the economic viability of rural communities.

Impacts on Organic Farmers

The survey asked whether organic farmers had experienced GE crop contamination and the rejection of a shipment of goods. Nationally, 2.2% of surveyed farmers reported having a shipment of product rejected due to GE crop contamination (N = 881). However, this rate of contamination is not uniform throughout the U.S. The North Central region had 6% of respondents report having a product shipment rejected due to GE crop contamination (*Figure E.2*).

Figure E.2.

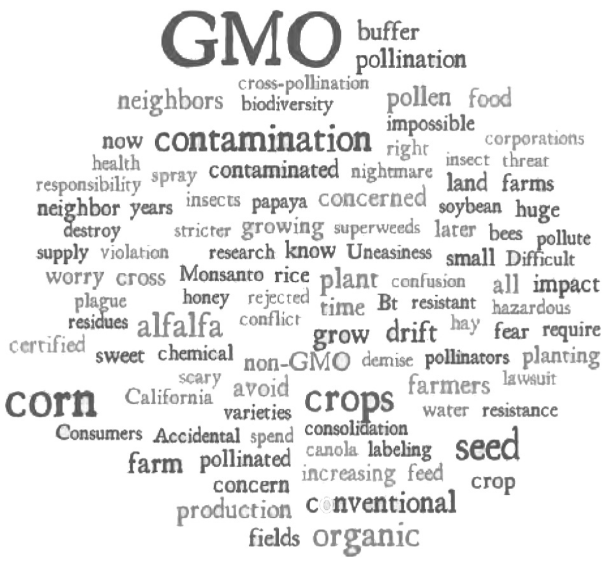


Regional distribution of organic rejections due to GE crop contamination (N = 881).

The survey asked farmers to describe the impact GE crops have had on their farm. The responses indicate that in addition to the direct financial impacts of having products rejected by buyers for failing to be GE free, organic farmers expressed a range of different ecological, financial, and psychological impacts from the threat of GE crop contamination. For example, one farmer stated, "We test before shipment and do not ship if contaminated. In the past our corn was highly contaminated by pollen from neighbors' GE corn. We treated it as hazardous material because we had no use on our farm for GE corn. The result was severe economic loss. We are committed to organic integrity." The 263 open-ended responses fall into several categories of impacts on farmers: pollen drift, delayed or altered planting, lost production, environmental pollution, increased pesticide pollution/drift, and psychological/emotional concern.

A word cloud created using keyword counts visually depicts the important terms represented in the survey (*Figure E.3*).

Figure E.3.



Word cloud for GE crop impact open-ended questions. The size of the word represents the number of times it was mentioned in the survey responses.

Concern

It was common for survey participants to express psychological distress related to GE crops. Words like worry, concern, fear, stress, and uneasiness were commonly used to describe the feelings the organic farmers had regarding GE impacts. One farmer stated, "I have constant stress due to possible cross contamination and fines for inadvertent violation." Farmers may also feel powerless when neighbors plant GE crops. One farmer stated, "A neighbor planted GMO (genetically modified organism) alfalfa right next to our alfalfa fields. We are asking ourselves: what do we do now??"

Pollen Drift

Many respondents mentioned pollen drift as a major impact on their farms. Responses included the need to monitor what their neighbors are planting. Corn and alfalfa are common crops for which farmers expressed concern for pollen drift. One farmer stated, "I am concerned that GMO pollen is contaminating my beehives and honey." One respondent stated, that they "always have fear that traveling pollen may impact our farm." Another farmer stated that they grow Indian corn for masa and animal feed, and that there is "always a threat of GMO contamination from wind borne pollen." Part of the problem with pollen drift is that many organic farmers are in proximity to conventional neighbors. This issue of contamination from adjacent fields was the most common concern expressed in the survey. One farmer stated that their 2013 corn crop was over 90% contaminated and their 2014 corn crop was 30–35% contaminated. Other responses included:

- "We watch and try to manage our crop rotation alternate to neighboring crops giving us less contamination, as a 25′ buffer/border is not enough to stop it."
- "We avoid growing corn on main farm site and try to time plantings on second farm site around the one corn grower."
- "Accidental spaying of herbicide on the comer of our field by neighbor resulting in buffer strip! We get GMO stalks and stover blown all over our property and all over our bottomlands with the yearly floods."
- "Sometimes have to adjust crop rotation schedule to avoid drift from one neighbor."
- "All my neighbors plant GMO so I am always concerned with cross-pollination."
- "We border a GMO corn and alfalfa grower. We worry about drift."

- "I am always concerned about GMO contamination, but we are currently surrounded by fallow land or woodlands, so it is not a big issue, but at anytime, someone could buy that land and put in GMO corn."
- "Concern over what, when and where my neighbors are planting."
- "Difficult to demonstrate buffer against contamination of surrounding conventional corn pollen. Try to have different tasseling dates compared to conventional neighbors, but this is not always possible."
- "We cannot grow sweet corn because we are surrounded by GMO corn."
- "An adjoining field raises conventional crops. Under current law and regulation, any contamination issues are our responsibility. The most significant impact on us is loss of production acreage, which is being used as a buffer."
- "We have had to purposely plant squash away from our neighbor's farm."
- "They are surrounding us, primarily GMO corn, and our main concern will be contamination of our alfalfa, over time, by GMO alfalfa."
- "We have apples and are concerned about the new GMO varieties due to cross-pollination."
- "GMO alfalfa is grown in our area, and impacts local hay; we try to grow all our own feed and not buy hay."

Seed Sourcing and Integrity

Many farmers expressed the difficulty in sourcing non-GE seed, or if they are seed producers, having their production at risk for contamination. Responses related to GE traits contaminating organic seed include:

- "We need stricter testing at the seed companies for GMO's in their organic seed."
- "We cannot grow seed crops for anything that could be pollinated by GM plants (corn)."
- "Seed industry consolidation . . . somewhat caused by introduction of GMOs in the marketplace, is affecting baseline prices and limiting the number of sources of availability."
- "We grow seed corn and are at risk."
- "I am concerned about feed fed to hens from organic supplier and increasing pressure to find appropriate layer pellets and scratch feed for hens. I am thinking I may source seed to sprout for my small flock—and am concerned about sourcing solid non-GMO seed for this purpose."
- "As more GMO crops are allowed it is also a nightmare to keep up with the paperwork saying the seed in non-GMO."
- "We are starting to grow our own alfalfa seed to avoid GMO contamination of alfalfa seed."
- "It is hard to get some of the corn varieties that interest me."
- "GMOs were very disruptive to our growing of chard seed."
- "As organic seed growers, in seed growing region we deal with isolation concerns all the time. As members in the Willamette Valley Specialty Seed Association (WVSSA) we participate in the pinning map system and respect our neighbors. We have GMO sugar beets being grown for seed in our area, which prevents us from growing any beta crops. So far we've succeeded in keeping GMO canola out of the valley, but if that ban is ever lifted, we'll be in trouble for all brassica production."
- "We cannot find non-GMO canola seed."
- "We bought organic seed, planted on organic land, had adequate space, about 1–2 miles from neighbors and still had some GMO contamination. We wonder about the organic seed being cleaned in elevators who also clean GMO seed."
- "It is impossible to find compostable carbon sources, *i.e.,* peanut hulls and cotton gin trash that is non-GMO."
- "Since papaya is pollinated via all means possible (wind, bees, birds, *etc.*) it is impossible to declare papaya GMO free. The fruit can be if tested in advance, but through pollination, the seeds cannot be so declared."

Environmental Impacts

Respondents often cited environmental impacts as a larger, ecosystem-wide way in which they are being affected by GE crops. The respondents cited impacts of bees and pollinators and water and air pollution from the increased use of pesticides like glyphosate. One farmer also mentioned that their personal health was being affected as a result of more intensive pesticide spraying. One farmer stated, "GMO crops often mean Roundup and other chemicals are being used to excess, and may runoff onto our land and end up in our water table. They impact the larger ecosystem of which our farm is but a small part."

Additional comments related to environmental impacts include:

- "Neighbors pollute my air with their glyphosate."
- "GMOs contribute to hazardous algae blooms and water contamination."
- "My apiary has ten beehives I manage for honey production and pollinator stability. I am concerned that GMO pollen is contaminating my beehives and honey. Is there an easy test for this? No."
- "I am concerned over the potential of resistant insects developed by GMO overuse becoming an issue."
- "I am worried about the potential loss of BT effectiveness."
- "Roundup resistant weeds that have become superweeds."

Societal Impacts

Many farmers expressed the idea that GE crops are having negative effects on the food system as a whole. These effects include consolidation of the agricultural industry as well as the legal ramifications for organic farmers if they experience GE crop contamination. For example, farmers stated:

- "GMOs have had a heavy effect on my community. Round Up Ready corn and beans have made for a huge consolidation of acres. The very large, 6–10,000 acre farming operations, don't have time for the community. Feed lot dairy has came to our region in the last 20 years replacing the many 50 to 100 cow, 200–500 acre dairy farms with 3,500 cow operations on 80 acres. These are huge changes, that I don't think would have been quite as extreme without GMOs."
- "Fewer farmers are covering more ground. I feel like I farm by myself."
- "I believe that the lawsuits that have prevailed to the demise of small farms are a shame to our history. Lawyers who have never farmed are controlling our food supply, and that is very scary to me."
- "The overall transformation of the global food system away from one in which local people buy food from local farmers."
- "We worry about the government siding with corporations instead of farmers and not allowing labeling or interfering with organic's right to say no to GMOs."
- "We need a major class action lawsuit against these companies for contamination of the seed supply and our soils."
- "Hawaii is trying to keep Monsanto off of the Island and out of Hawaii. I have attended many Community/County Council meetings."

Monetary Costs

As a result of GE crop contamination of organic products, organic farmers have suffered financially due to displaced planting schedules, loss of revenue due to project rejection, decreased yield due to buffer areas, and the loss of certain marketing opportunities (like the European markets which have zero contamination standards). Economic losses reported in the survey include:

- "I tried sweet corn seed and it was contaminated by Roundup ready corn in the area—lost the sale."
- "It is becoming increasingly impossible to maintain zero contamination as is required in European markets."
- "An adjoining field raises conventional crops. Under current law and regulation, any contamination issues are our responsibility. The most significant impact on us is loss of production acreage which is being used as a buffer."
- "Decreases in yields due to missing optimum planting windows for crops in order to avoid contamination. As more GMO crops are allowed it is also a nightmare to keep up with the paperwork saying the seed in non-GMO."
- "Lost production due to sizable buffer strips."
- "We have to plant later to prevent cross-pollination. This has really hurt us on particular years."
- "Sometimes have to adjust crop rotation schedule to avoid drift from one neighbor."
- "Loss of organic premiums."
- "Lower yields from later planting."

- "Insect pressure from conventional fields."
- "Corn that was sold for food grade and had a 1.2% GMO detection and it needed to be less than 1%."
- "All of my 2014 corn crop was rejected for the food grade market due to contamination that came in from most likely my neighbor's corn field. Non-organic corn pollinated later than usual last year due to a cool spring and summer which overlapped into my pollination window I always plant my corn much later although due to what I mentioned above caused a huge negative impact for me."
- "We spend money on testing, which Monsanto should be paying."
- "Increasing the buffer areas therefore decreasing the land that cam be certified as organic."

Customer Confusion

Many farmers stated that customer confusion about organic products, GMOs, and GE free products as hurting their marketing. Comments addressing customer confusion include:

- "We get a lot of customers very concerned that we are growing GM grass or alfalfa for our cows. One of the reasons we certify as much of our pasture as we can is for this reason."
- "Consumer confusion regarding the allowance by USDA to grow the GMO Arctic varieties. They don't realize the 'organic' means GMO free."
- "Consumers don't realize the Certified Organic seal is better than a non-GMO seal."
- "We need to certify products as GMO free for marketing reasons."

Conclusions

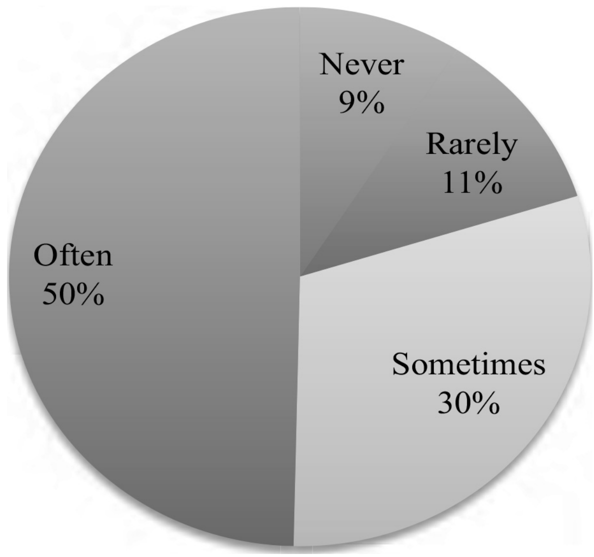
The comments from organic growers depicting the impacts from GE crops highlights the need for greater education, research, and policy interventions. Education and training for both organic and conventional farmers is needed on best practices to avoid GE crop contamination of organic crops. Research and monitoring on the magnitude of GE crop contamination is needed at both regional and national scales. Research on the efficacy of different avoidance practices should be a focus of future research. There is a need for stronger U.S. policies designed to protect organic farmers from GE pollen drift and reduce the economic hardships caused by GE crop contamination avoidance practices.

Appendix F: Seeds

Seed Availability

According to the National Organic Program guidelines, organic farmers must use organic seed when it is commercially available. However, if the desired organically produced seed or planting stock variety is commercially unavailable, organic farmers may use conventionally grown, untreated seeds. To assess the availability of organic seed, we asked the survey participants to categorize the frequency of organic seed availability for the primary crops they grow. The survey found that for 20% of respondents, organic seed was rarely or never available (*Figure F.1*). There were some regional differences. Farmers in the Western region reporting less organic seed availability; reporting that organic seed was never available 14% of the time.

Figure F.1.



Frequency of organic seed availability as reported by U.S. organic farmers.

Farmers reported several major areas of concern regarding organic seed. The biggest challenge reported was the price of organic seed being much higher than non-organic seed. Other major challenges are the quality and regional and temporal unavailability. As a result of challenges regarding the availability of organic seed, many surveyed farmers reported doing their own seed saving. One farmer described the disadvantage small organic farmers face with obtaining organic seed in a rural market. They stated, "Many of the large agricultural product cooperatives through which rural people source feed and seed do not carry organic seed as a standard. They require the purchase of a full semi load to even consider making the order. Small- and mid-scale operations struggle to gain affordable access to untreated, non-GMO, and certified organic field seed."

Price

The higher price for organic seed was the most common challenge reported by growers in the survey. The large price discrepancy between organic and conventional seed is a disincentive for farmers to use organic seed. The survey recipients expressed the issue that high organic seed cost is interfering with profit, and that price is an important factor with regards to seed sourcing. Several farmers also expressed an understanding that the limited number of organic seed distributors is helping to create the situation of high prices for organic seed. Responses related to the high price of organic seed include:

- "Production hasn't reached the place where it is economically feasible to plant certified organic seed."
- "We grow about 100 vegetable varieties, and all but about six are available as certified organic seed. However, we have stopped growing certain organic transplant crops (Brussels Sprouts, for one) because the seed has become so expensive we cannot sell tray packs of the starts. The price rises in organic seed in the past 4–6 years are very large, especially since in our region there is no price premium for organic vegetable transplants."
- "Would like to see affordable organic strawberry plants."
- "Cost is more of problem than availability—at least for small grains and forages."
- "It is difficult to obtain small quantities of organic seed—many suppliers have astronomical prices for small quantities and the 'next size up' is huge and **way** out of practical for small farmers. "

- "Organic nursery stock is unavailable for the latest commercial fruit tree varieties. The few that are available are insanely expensive and geared toward the home garden market."
- "Organic seed is usually available, even though I may have to order online instead of local availability. But the price is sometimes many times more expensive. Example organic soybeans ($50/lb.), non-treated soybeans ($3/lb.)."
- "Organic seed costs are triple and quadruple sometimes their untreated counterparts, to remain profitable it's very hard to purchase all of your seed organic, but this is not acceptable to NOP and certifying bodies."
- "If it wasn't for a local organic farmer who saves his own seed, purchasing organic wheat, rye, and soybeans would be cost prohibitive."
- "Why do they have to cost so much? Makes it hard to turn profit when I am paying over $410/LB for organic grass seed!?"
- "Honestly—the less organic seed available the better—it's very expensive and cuts into our profitability, plus the quality is often inferior. We would feel very differently if there were cultivars developed specifically to thrive under organic management because the additional cost would be offset by increased productivity."
- "When we were conventional we spent $60,000 a year on fertilizers and sprays. Now that money is all spent on seeds and soil amendments."

Quality

Survey respondents reported that the quality of organic seed was often inferior to conventional seed in terms of germination rate, yield, vigor, and contamination with weed seeds. Respondents also reported that there are fewer organic seed varieties to choose from. Organic farmers need varieties specific to their needs, such as high nutrient-use efficiency, disease resistance, insect resistance, weed competition, and are of good quality. Although there has been progress in seed breeding for organic production, it is a slow process and some farmers report dissatisfaction with organic seed germination rates. Respondent comments regarding the quality of organic seed include:

- "Organic seeds for the most part are open-pollinated older varieties which don't have the appeal or plant vigor of the commercial conventional seeds."
- "Want newer varieties."
- "In many crops we are generally disappointed with the organic varieties either due to yield or traits."
- "We like good disease resistance, yield, flavor and some capacity for shipping and shelf life."
- "Most companies aren't interested in developing drought resistant varieties with characteristics we need for organic."
- "The genetics are horrible—conventional non treated non-GMO, always out yields organic hybrids."
- "Need to develop better grasses."
- "The wonderful varieties of bell peppers, eggplant, cucumbers, and round tomatoes that are conventionally available are generally unavailable organically. This is very frustrating, as our certifier wants us to have 70% organic seed."
- "Not enough quantity or variety! I often have to use non-organic seed because the organic varieties aren't as developed or as good."
- "Many seed varieties don't yield enough product. This means I have to grow more, which uses more water, seed, labor and land space. Not cost effective."
- "Because we farm in an area that is dominated by large production vegetable farms there are lots of disease inoculum present throughout much of the year. As such, we often rely on 'cutting edge' varieties that resist the latest races of prevalent diseases, but for the most part, they are not available from organic seed."

Availability

Many farmers reported that organic seed was not available locally in their area for certain crops, or became harder to find during the peak of the planting and growing season. There were several crops for which respondents reported very little availability, specifically grass, cover crops, kale, and flower seeds. Comments related to the lack of availability of organic seed include:

- "There's a need for cover crop seed."

- "Open pollinated, drought tolerant grain sorghum (milo) is generally not available."
- "Not much for selection in corn and alfalfa. Never find organic seed for grasses. Sometimes clover is available. Organic oat seed is sporadically available."
- "Sweet corn for the south is hard to find. Silver Queen grows best but none available organically. Sun Gold tomatoes a must for markets but not available organically. Cover crop seed is expensive and almost prohibitive with shipping cost."
- "I use tree planting stock. Organically raised trees are almost impossible to find here in CA."
- "Seed sources for herbs is very limited for specialty crops. Also, seed quantity is often limited, and suppliers rarely offer bulk pricing. Finally, we have had minor problems with mislabeling and/or unknowingly cross pollinating species, resulting in the wrong species."
- "Need more variety development in carrot seed, onion seed, radish and corn seed. There was a nation-wide lack of Breen (mini red romaine) lettuce and curly blue kale. As bigger farms get into organic they are pushing the rest of us around, buying up limited seed, hogging up larger markets, pushing prices down."
- "As for flowers (we sell seedlings) there is almost no significant availability of organic seed. I don't know why, but that is a big area of need."
- "Organic sunflower seed has doubled in price and become much less available."
- "It's almost impossible to find organic pasture mixes or even dryland cover crops, or specific to your area strains of wheat, sudan, bmr sorghum, alfalfa, *etc.* (Strains that the other conventional growers near you have access to but you don't because there isn't an organic version)."
- "There is only one known organic spawn for mushrooms and it is not commercially acceptable. There needs to be more research and development for this."

Specific Areas of Need

Surveyed farmers highlighted several areas for which there is a need for more research or policy change regarding organic seed. Farmers commonly stated the need for increased on-farm breeding and variety improvement for organic seeds for the development of more organic hybrids for disease resistance. Farmers also expressed different views related to the policy for organic seed sourcing. Several farmers stated the need for stricter enforcement of using organic seed. For example, farmers stated:

- "If we did not allow conventional seed at all, we would all whine and complain, but then we would have to pay for it, the companies would contract with farmers to grow it for seed, and it would be done. Just like the conventional guys."
- "We need to continue to pressure farms to use organic seed and trial organic varieties to replace their conventional untreated varieties. To be organic you must use organic seed."
- "As long as organic crops can be grown from non-organic seed, there is little incentive to develop a reliable seed production infrastructure. The 'loophole' in standards should be closed over a 10 year period to allow and incentive necessary development of an organic seed system."

Farmers also expressed the need for new priorities for the seed breeding industry and university breeders. One farmer stated that wheat varieties currently are "short wheat, short root systems, lower protein and mineral content, higher nitrogen needs, are really not what we need." The farmer expressed the need for breeding that focuses on good root systems for interacting with healthy organic soil (rather than depleted conventional soil). Another farmer stated that they are very concerned about the loss of public seed varieties and declines in non-GMO seed varieties, particularly with soybeans. The farmer stated, "I am also very concerned about the widespread GMO contamination potential from GMO alfalfa. GMO wheat could be a disaster as well I think the availability of public varieties and farmers ability to save and reuse their own seed is fundamental to agricultural sustainability." Farmers expressed the need for universities to rebuild their public variety development and distribution systems.

Farmers expressed the need for growth in the number of organic seed producers and distributors in order to supply seed at a lower price and in more varieties. One farmer pointed out that lowering the high cost of organic seed is one possible opportunity to change the organic industry and encourage greater adoption of organic farming. "Lower cost of organic seed would lead to better availability of product and better economics for smaller producers. This would entice more folks to grow organic." Another farmer stated, "Sometimes it feels like all the farmers are buying from the same handful of seed companies which makes it feel like nobody is growing anything very special or unique. It would be great if more 'local' and regional variety began to emerge which would add a level of depth to the organic food system and a nice sense of local identity for farming communities around the country."

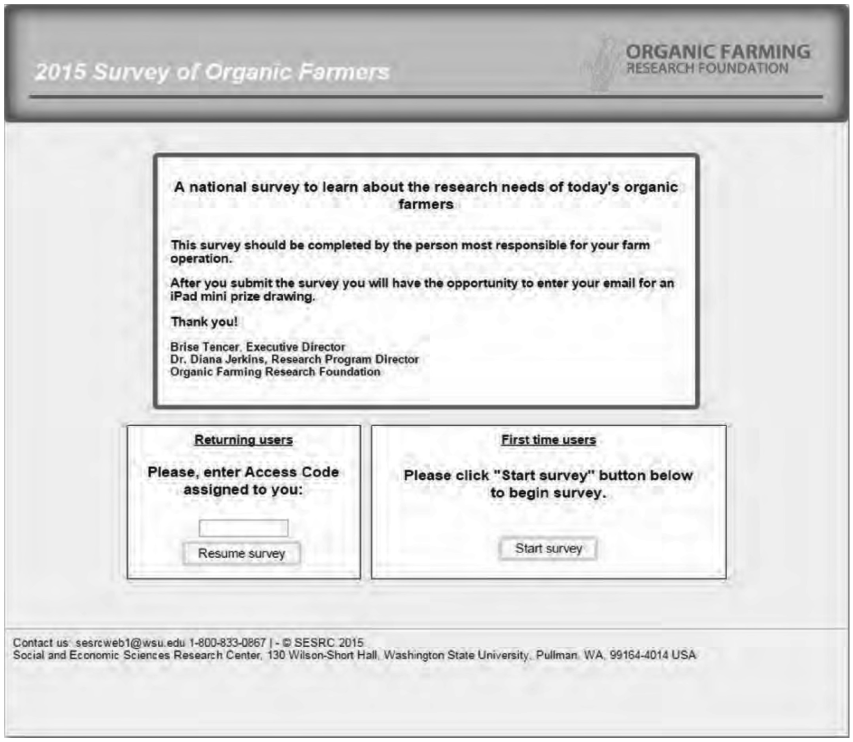
Appendix G: Listening Sessions 2015–2016

Twenty-one listening sessions were held in 2015 and 2016 to inform the 2015 National Organic Research Agenda report. The following list contains the names and locations of the meetings where the listening sessions were held.

- Midwest Organic & Sustainable Education Service (MOSES) Conference, (Midwest/Wisconsin) (2015 and 2016)
- Ecological Farming Conference, (West/California) (2015 and 2016)
- Virginia Biological Farmers Association, (East/Virginia)
- North East Sustainable Agriculture Working Group Conference, (East/New York)
- Minnesota Organic Conference in 2015, (Central/Minnesota)
- Organicology Conference (West/Oregon)
- Organic Agriculture Research Symposium, (West/Wisconsin)
- Southern Sustainable Agriculture Working Group Conference (SSAWG), (South/Alabama)
- Pennsylvania Association for Sustainable Agriculture (PASA), (South/Pennsylvania)
- Ohio Ecological Food and Farm Association (OEFFA), (Central/Ohio)
- Organic Seed Alliance Conference, (West/Oregon)
- National Sustainable Agriculture Coalition (NSAC) (East/Washington, D.C.)
- Idaho Organic Growers Conference, (Central/Idaho)
- Natural Products Expo East, (East/Maryland)
- Organic Trade Association, Organic Confluences Summit (East/Washington, D.C.)
- California Certified Organic Farmers (CCOF) meetings, (three meetings; West/California)

Appendix H: Web Survey Instrument

Questions from the 2015 National Organic Farmer Survey



2015 Survey of Organic Farmers

ORGANIC FARMING
RESEARCH FOUNDATION

A national survey to learn about the research needs of today's organic farmers

This survey should be completed by the person most responsible for your farm operation.

After you submit the survey you will have the opportunity to enter your email for an iPad mini prize drawing.

Thank you!

Brise Tencer, Executive Director
Dr. Diana Jerkins, Research Program Director
Organic Farming Research Foundation

Returning users

Please, enter Access Code assigned to you:

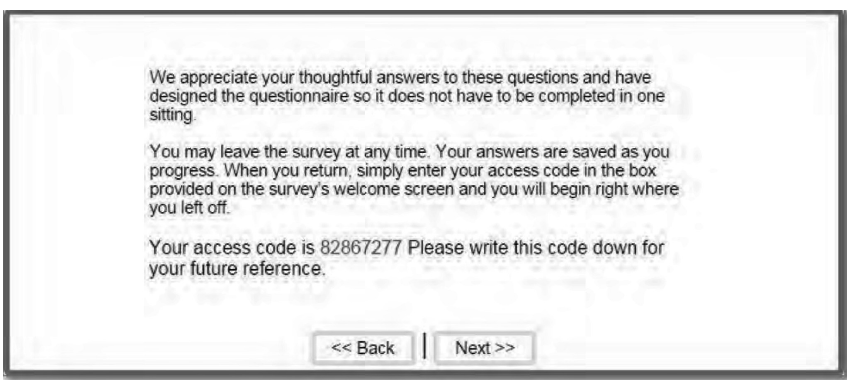
Resume survey

First time users

Please click "Start survey" button below to begin survey.

Start survey

Contact us: sesrcweb1@wsu.edu 1-800-833-0867 | - © SESRC 2015
Social and Economic Sciences Research Center, 130 Wilson-Short Hall, Washington State University, Pullman, WA, 99164-4014 USA



We appreciate your thoughtful answers to these questions and have designed the questionnaire so it does not have to be completed in one sitting.

You may leave the survey at any time. Your answers are saved as you progress. When you return, simply enter your access code in the box provided on the survey's welcome screen and you will begin right where you left off.

Your access code is 82867277 Please write this code down for your future reference.

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Question 1 of 34

Do you operate a farm that produces and markets certified organic products?

- Yes
- No

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Question 2 of 34

First, we'd like to start with some questions that will help us learn a little bit about you and your farm.

a. How many years have you been farming? ____ Years
b. How many years have you been farming organically? ____ Years
c. How many total acres do you farm including both owned and leased, organic and conventional? ____ Acres
d. How many acres do you farm organically? ____ Acres

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Question 3 of 34

In which of the following ways did you begin farming organically? *(Select one response.)*

- Transitioned from conventional farming practices
- Did not transition: began farming using organic practices
- Other, please explain: ____

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Question 4 of 34

Does your farm have acres in any of the following categories?

	Yes	No
Certified organic *Name of certifying agency* ____	○	○
Organic and exempt from certification (sales are less than $5,000)	○	○
Farming practices compatible with NOP guidelines but not certified	○	○
Transitioning to certified organic	○	○
Conventional	○	○
Other, please specify: ____	○	○

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Question 5 of 34

In what state(s) is your farm is located?

Primary state farm is located	**If your farm is located in a second state, please select it from this list.**
-- Primary State -- ▾	-- Secondary State -- ▾

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Question 6 of 34

How much of a priority is each of the following soil research topics to you?

	High priority	Moderate priority	Low priority	Not applicable
Soil health, biology, quality and nutrient cycling	○	○	○	○
Soil conservation and restoration	○	○	○	○
Fertility management	○	○	○	○
Other, please specify:	○	○	○	○

Please describe your specific informational needs related to soil research.

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Question 7 of 34

How much of a priority is each of the following farming practices research topics to you?

	High priority	Moderate priority	Low priority	Not applicable
Breeding of crops, animals, and seeds for organic production	○	○	○	○
Crop rotations	○	○	○	○
Grazing and pasture management	○	○	○	○
Integration of perennials in organic farming systems and permaculture design	○	○	○	○
Food safety issues	○	○	○	○
Specific production system methods and practices and on-farm research	○	○	○	○
Irrigation and water use, drought management	○	○	○	○
Cover cropping and green manures	○	○	○	○
Post-harvest handling methods	○	○	○	○
Other, please specify:	○	○	○	○

Please describe your specific informational needs related to farming practices research.

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Question 8 of 34

How much of a priority is each of the following weed, pest, and disease research topics to you?

	High priority	Moderate priority	Low priority	Not applicable
Weed management	○	○	○	○
Insect management	○	○	○	○
Disease management	○	○	○	○
Other, please specify:	○	○	○	○

Please describe your specific informational needs related to weed, pest, and disease research.

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Question 9 of 34

How much of a priority is each of the following environmental research topics to you?

	High priority	Moderate priority	Low priority	Not applicable
Ecosystem services (biodiversity, water quality/quantity, soil retention) provided by organic systems				
Impact of GMO crops on production practices, sales, markets, and seed availability				
Pollinator health				
Fluctuations in temperature and rainfall adaptation and mitigation				
Other, please specify:				

Please describe your specific informational needs related to environmental research.

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Question 10 of 34

How much of a priority is each of the following societal and economic research topics to you?

	High priority	Moderate priority	Low priority	Not applicable
Organic agriculture's impact on rural communities				
Certification and labeling				
Organic farm economics, marketing and consumer behavior				
Value added production and processing without synthetic additives and processing aids				
Nutritional quality, health benefits and integrity of organic food				
Other, please specify:				

Please describe your specific informational needs related to societal and economic research.

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Question 11 of 34

From the list of research topics you selected in the previous question, which three are the highest priorities for you? *(Please select up to 3 topics)*

- Other societal and economic research topic

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Note: At *Question 11* the survey displayed only the topics selected with a high, moderate or low priority in *Questions 6* through *Question 10,* including the text from any of the "Other" categories. Additionally, this page only allowed up to three selections.

Question 12 of 34

Of the following research topics, which one has the highest priority for you?

- Soil health
- Farming practices
- Weed, pest, and disease management
- Environmental factors
- Rural societies and economics

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Question 13 of 34

What is your most pressing production issue right now? *Please describe.*

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Question 14 of 34

How useful to you is production research in making management decisions for your organic farm?

- Very useful
- Somewhat useful
- Slightly useful
- Not at all usefull

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Question 15 of 34

Are you currently doing any experimentation or trying new practices on your farm?

- Yes, what type of experiments?
- No

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Question 16 of 34

What is your primary source of organic production and marketing information? *Please describe.*

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Question 17 of 34

How useful have each of the following INFORMATION RESOURCES been to you in obtaining information about ORGANIC PRODUCTION and/or MARKETING? *Please mark "Haven't used" for those resources you have never used.*

Resource	Haven't used this resource	Not at all useful	Slightly useful	Mostly useful	Highly useful
Cooperative Extension personnel	○	○	○	○	○
Cooperative Extension publications	○	○	○	○	○
University-based researchers or educators	○	○	○	○	○
University-based publications	○	○	○	○	○
Crop consultants	○	○	○	○	○
Other farmers	○	○	○	○	○
Growers' associations	○	○	○	○	○
Non-profit organizations	○	○	○	○	○
Organic certifier	○	○	○	○	○
State agriculture department	○	○	○	○	○
USDA	○	○	○	○	○
Buyers	○	○	○	○	○
Suppliers	○	○	○	○	○
Other, please specify:	○	○	○	○	○

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Question 18 of 34

How much do you prefer each of the following INFORMATION FORMATS for information about ORGANIC PRODUCTION and/or MARKETING. *For those formats you have not used, please mark "Have not used".*

Information format	Have not used this format	Do not prefer	Slightly prefer	Mostly prefer	Highly prefer
Farming & gardening books	○	○	○	○	○
Printed handbooks/manuals	○	○	○	○	○
Online handbooks/manuals	○	○	○	○	○
Print periodicals (newspapers, magazines, newsletters)	○	○	○	○	○
Email newsletters	○	○	○	○	○
Email groups & listserves	○	○	○	○	○
Internet websites	○	○	○	○	○
Webinars (Online seminars)	○	○	○	○	○
Seminars	○	○	○	○	○
Conferences & workshops	○	○	○	○	○
Classes and/or coursework	○	○	○	○	○
Field days, on-farm demonstrations	○	○	○	○	○
Social media (Facebook/Twitter, etc.)	○	○	○	○	○
Radio programs	○	○	○	○	○
Podcasts	○	○	○	○	○
Online videos (YouTube, etc.)	○	○	○	○	○
CDs	○	○	○	○	○
DVDs	○	○	○	○	○
Films or documentaries	○	○	○	○	○
Scientific journals	○	○	○	○	○
Other, please explain: ______	○	○	○	○	○

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Question 19 of 34

What are your current marketing outlets? *Please indicate yes or no for each one.*

	Yes	No
Direct to consumer		
Farmers market	○	○
CSA	○	○
On-farm sales/U Pick	○	○
Website sales	○	○
Other direct to consumer, please list: ______	○	○
Direct to retail		
Local food store/cooperative	○	○
Chain food store/supermarket	○	○
Restaurants	○	○
Other direct to retail, please list: ______	○	○
Wholesale		
Store, please specify: ______	○	○
Processor/packer	○	○
Private grain elevator	○	○
Handler/broker	○	○
Cooperatives	○	○
Other wholesale, please list: ______	○	○

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What is your most pressing marketing issue right now?

What marketing research would help you the most?

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Question 21 of 34

How often do you use each of the following fertilization/fertility management strategies and materials?

	Never	Rarely	Occasionally	Frequently	Regularly
Cover crops	○	○	○	○	○
Compost	○	○	○	○	○
Gypsum or lime	○	○	○	○	○
Animal byproducts (such as fish products, bone or blood meal, feather meal, etc.)	○	○	○	○	○
Kelp or seaweed	○	○	○	○	○
Minerals (other than gypsum and lime)	○	○	○	○	○
Raw manure	○	○	○	○	○
Compost tea	○	○	○	○	○
Other, please list	○	○	○	○	○

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Question 22 of 34

How would you rate availability of certified organic seed for the primary crops you grow?

- Never available
- Rarely available
- Sometimes available
- Often available
- Always available

Please tell us any thoughts you may want to share regarding the availability and qualtiy of organic seed for your primary crops.

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Question 23 of 34

If you are a grain producer, what is your challenge to increasing organic production?

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To the best of your knowledge, have you ever had a shipment of product rejected due to GMO contamination?

- Yes
- No

Please describe any other impacts GMOs have had on your farm.

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Question 25 of 34

Within the last five years, did you lose sales or certification on any organic land due to pesticide spray drift?

- Yes, which crops did you lose?
  and how many acres did you lose?
- No

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Question 26 of 34

How familiar are you with the new Food Safety Modernization Act that is going into effect over the next few years?

- Not at all familiar
- A little familiar
- Somewhat familiar
- Very familiar

How much impact do you think the new food safety regulations will have on your farm?

- No impact
- Slight impact
- Some impact
- Great impact

Please describe the ways you think the new food safety regulations will impact your farm.

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Question 27 of 34

Which of the following categories of crops are organically grown on your farm for market? *(Please select yes or no for each.)*

☐ Please check this box if you do not grow any organic crops for market.

	Yes	No
Vegetables	○	○
Herbs	○	○
Flowers	○	○
Nursery/greenhouse crops	○	○
Tree fruit	○	○
Small fruit	○	○
Vineyard	○	○
Field corn	○	○
Soybean	○	○
Rice	○	○
Cotton	○	○
Alfalfa/mixed hay	○	○
Small grains/beans/other field crops	○	○
Forage/pasture	○	○
Mushrooms	○	○
Other, please list: ______	○	○

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Question 28 of 34

Which of the following categories of animals or animal products are organically grown on your farm for market? *(Please select yes or no for each.)*

☐ Please check this box if you do not produce any organically grown animals or animal products for market.

	Yes	No
Poultry	○	○
Eggs	○	○
Beef	○	○
Sheep/lambs	○	○
Pigs/pork	○	○
Dairy	○	○
Honey	○	○
Other, please list: ______	○	○

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Does your farm produce value-added products? *(e.g. preserves, juices, dried fruit or nuts, cleaned and bagged grains, processed meats, etc.)*

○ Yes, which ones (please specify): ______

○ No

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Question 30 of 34

What percentage of your net income came from organic farm production in 2014?

- None (no profit or loss)
- 1% - 25%
- 26% - 50%
- 51% - 75%
- 76% - 100%

Does anyone work off-farm more than 20 hours a week?

- Yes
- No

Do you or your employees have access to health insurance?

- Yes
- No

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Question 31 of 34

What was your farm's gross organic farming income in 2014? *NOTE: All survey responses, including financial figures, are strictly confidential.)*

- No income or loss
- Less than $5,000
- $5,000 to $14,999
- $15,000 to $29,999
- $30,000 to $49,999
- $50,000 to $99,999
- $100,000 to $249,999
- $250,000 to $499,999
- $500,000 to $999,999
- $1million TO $4.9 million
- 5 million to $19.9 million
- Over $20 million

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What is your age?

[ ] Years of age

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What is your level of formal education?

- Less than high school
- High school / GED
- Some college
- 2-year college degree
- 4-year college degree
- Master's Degree
- Doctoral degree (PhD)
- Professional degree (MD, JD)

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Are you . . .

- Male
- Female

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Thank you for your participation in the OFRF 2015 Survey of Organic Farmers.

1. To be entered into the drawing for an iPad mini, enter your email address here:

 email address

2. If you are interested in cooperating with research scientists on organic farming research, enter an email address here:

 email address

*Providing your email opts you in to receive the survey results and other news from OFRF. Your email address is in no way associated with your survey response.

If you have additional comments you would like to make about organic farming or provide additional feedback regarding this survey, please note them here.

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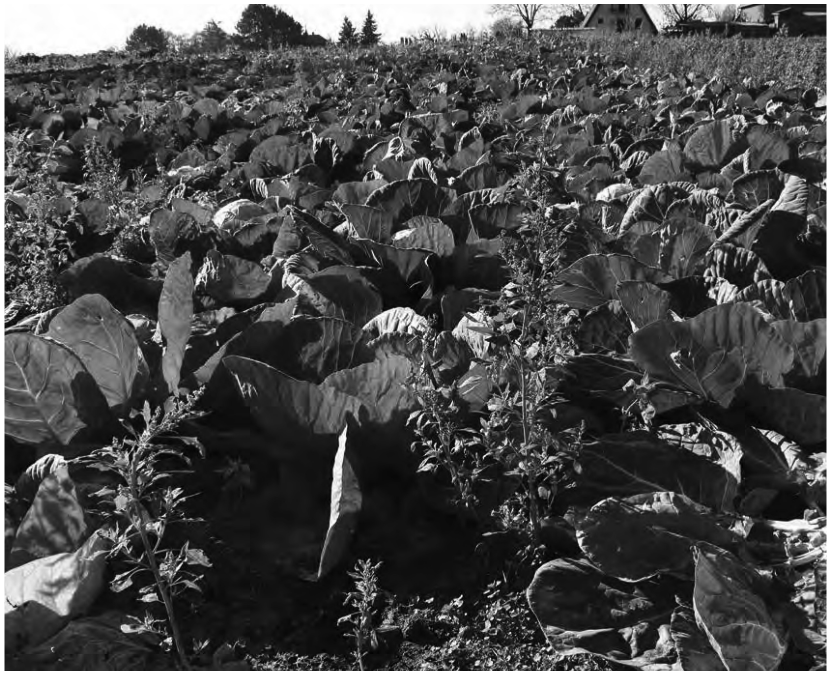
You are about to finish this survey.
To submit the survey click "Submit survey" button below.
To review your answers starting from the begining click "Review your answers" button.

Submit survey | Review your answers

REPORT 2

Reducing Risk through Best Soil Health Management Practices in Organic Crop Production



By Mark Schonbeck & Michael Stein

View more reports at: *http://ofrf.org/reports*

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Introduction

The purpose of this guide is to provide farmers with research-based information and resources to help identify and implement effective soil health based risk reduction practices. The companion guide, *Introduction to Crop Insurance for Organic and Transitioning Producers,* provides information on how crop insurance works and how to determine which crop insurance options are right for your operation.

Farmers must manage an array of risks. Production risks include yield losses resulting from poor germination and establishment; drought, hail, and other adverse weather events; weeds, pests, and diseases; nutrient limitations; and long-term declines in productivity related to soil erosion, compaction, or degradation. Climate change is expected to exacerbate risks by intensifying weather extremes, modifying life cycles of crop pests and pathogens, and accelerating decomposition of soil organic matter (SOM) (IPCC 2014, Kirschbaum, 1995).

Financial risks arise when total costs of production, including seed, fertilizers and other inputs, labor, field operations, and fixed costs (*e.g.,* loan payments), exceed gross proceeds as determined by yields and market prices. Careful evaluation of economic risks becomes especially important when you diversify crops or enterprises, adopt new practices for soil health or other objectives, or undertake transition to organic production. Farmers can also face legal, regulatory, and human health risks related to food safety, water quality and other environmental impacts of farming practices.

Strong market demand and high prices for certified organic farm products can help reduce economic risks for organic producers, and organic price elections (somewhat reflecting organic prices) are available for insurance of some crops in certain areas (Schahczenski, 2018a). However, without the use of synthetic fertilizers, herbicides, and pesticides, organic farmers face increased risks of crop losses to nutrient deficiencies especially nitrogen (N), weed competition, insect pests, and diseases. Compared to conventional systems, organic crop production depends more heavily on soil biological processes to provide crop nutrition and sustain yields. Building and maintaining a healthy soil—rich in organic matter and beneficial organisms—is a top management priority.

Why Soil Health is Important to Production

Soil health plays a key role in reducing production costs and risks (*Table 1*). Healthy soil enhances crop resilience to drought, pests, and other stresses; and thereby minimizes losses during “bad” years. For example, while organic and conventional crop rotations in the Rodale long-term farming systems trials gave similar yields over a 35 year period, the organic systems sustained much better crop condition and 31% higher grain yield in corn during drought years (Rodale, 2011a, 2015). Higher soil organic matter, biological activity, and moisture infiltration and storage in the organic systems resulted in greater yield stability.

Healthy soils with optimum soil organic matter (SOM) content and biological activity develop good structure (tilth) with reduced surface crusting and compaction, and ample interconnected macro and micro pore spaces extending deep into the soil profile. Desirable soil test SOM levels vary with soil texture and climate, from ~2% in Southeastern U.S. coastal plain sandy loams, to ~6% or more in Northern Corn Belt clay loams (Magdoff and van Es., 2009). Such soils drain well, maintain sufficient aeration, and readily absorb, retain, and deliver plant-available moisture. In addition to sustaining crops through dry spells, healthy soils undergo less ponding, runoff, and erosion during heavy rains (Magdoff and van Es, 2009; Moncada and Sheaffer, 2010; Rodale, 2015).

Table 1. How healthy soil reduces risks in organic crop production

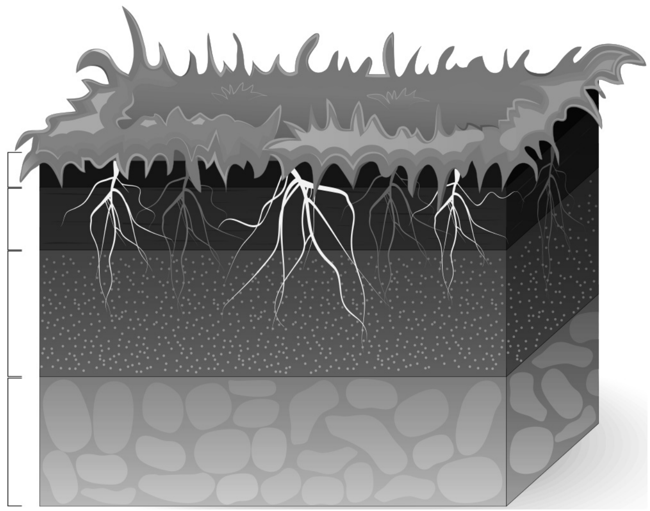
Functions of a Healthy Soil	Risks and Costs Mitigated
Maintains good structure (tilth). Accrues and maintains stable organic matter.	Requires less tillage to make seedbed. Easy to work. Improves crop emergence and establishment. Cultivation for weed control is more effective.
Drains well.	Provides yield stability in wet years, and less root disease. Reduces delays in planting and other field operations.
Resists erosion, crusting, and compaction; recovers from tillage and other stresses.	Increases soil and crop resilience to weather extremes. Reduces risk of losing fertile topsoil.
Absorbs, retains, and delivers plant-available moisture.	Provides yield stability in drought years. Reduces need for irrigation. Reduces runoff and erosion; protects water quality.
Retains and recycles nitrogen and other nutrients. Maintains sufficient but not excessive levels of plant-available nutrients.	Maintains crop yield and quality. Reduces fertilizer needs. Reduces nutrient losses. Protects water quality.
Hosts abundant, diverse, beneficial organisms; harbors few pests or pathogens	Reduces risk of crop losses to diseases and pests.

Good soil structure facilitates planting, crop emergence, and stand establishment; improves efficacy of cultivation for weed control, and may reduce the number of passes needed. In addition, as soil physical condition improves, crop roots extend deeper into the soil profile, thereby relieving subsurface hardpan and enhancing the soil’s plant-available water holding capacity by building SOM below the plow layer (Rodale, 2015).

Abundant, active, and diverse soil life in healthy soils enhance the release of N and other nutrients from crop residues, active SOM, and organic amendments (Wander, 2015b; Wander, *et al.,* 2016). Healthy soils promote mycorrhizal (fungus-root) symbioses and other beneficial root-microbe associations that aid crop uptake of nutrients and moisture (Hamel, 2004). These biological processes, combined with deeper and larger root systems, reduce the amount of fertilizer and irrigation needed to sustain yields, and mitigate environmental and regulatory risks related to soluble N and phosphorus (P) losses to ground and surface waters (Kloot, 2018; Rosolem, *et al.,* 2017; Sullivan, *et al.,* 2017).

A diverse and balanced soil microbiota can suppress plant pathogenic fungi, bacteria, and nematodes, thereby reducing risks of crop losses to diseases (Baker, 2016). Beneficial soil fungi can also induce systemic resistance (ISR) to foliar pathogens, such as late blight and gray mold in tomato (Egel, *et al.,* 2018).

Challenges and Opportunities in Co-Managing Soil Health and Production Risks



While optimum soil health in itself generally reduces production costs and risks (*Table 1*), management practices adopted to improve soil health can add new costs and risks as well as benefits, especially for organic producers (*Table 2*). The National Organic Standards require certified organic producers to make a long-term investment in soil health (see *Concept #1*). One challenge faced by all farmers is how to put a dollar value on soil health benefits, especially since financial returns (yield) on this investment can take 5 or 10 years to accrue.

Table 2. Benefits, risks, and costs associated with soil health management practices in organic systems

Practice	Benefits	Costs and Risks
Cover crop	Reduces erosion. Adds organic matter, feeds soil life. Fixes N (legumes). Recovers and retains nutrients. Suppresses weeds.	Consumes soil moisture. Can delay cash crop planting. Can tie up N (non-legumes). Can leach N (legumes, crucifers). Adds costs for seed and planting.
Diversified crop rotation	Enhances soil microbial diversity. Reduces weeds, pests, and diseases. Opens new market opportunities.	New crops entail marketing challenges. Increases system complexity. May require new equipment and skills.
Sod crop in rotation	Prevents erosion during sod phase. Depletes annual weed seed banks. Restores soil health and fertility.	Sod years may entail foregone income. Tillage usually needed to break sod.
Minimum tillage	Conserves soil organic matter. Conserves soil structure. Reduces erosion.	Often increases weed pressure. Can delay N release to cash crops. Can complicate crop establishment. Require new equipment and skills.
Compost and other organic amendments	Adds and stabilizes organic matter. Provides slow-release nutrients.	Can build excess P or other nutrients Some amendments can leach N. Manure can pose food safety risks. Adds purchase and shipping costs.

Organic farmers face a somewhat different suite of production risks from conventional farmers. Yields of organically produced corn, soybean, and other field crops average about 19% lower than conventional yields (Ponisio, *et al.,* 2014). Leading causes of this yield gap include insufficient plant-available N (Caldwell, *et al.,* 2012), increased weed pressure (Hooks, *et al.,* 2016), and challenges in managing pests and diseases without synthetic crop protection chemicals (Jerkins and Ory, 2016). The historical lack of research investment in organic agriculture and development of crop cultivars suited to organic systems have contributed to lower organic yields (Hultengren, *et al.,* 2016; Ponisio, *et al.,* 2014). Although USDA organic research funding still lags behind the 5% organic market share in the U.S. food system, the Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) have begun to address many organic farmers' research priorities (Schonbeck, *et al.,* 2016).

Exclusion of synthetic inputs from organic systems can reduce or offset certain production and economic risks. Consumer demand for food grown without pesticide sprays and with environmentally benign practices has led to higher prices for organic farm products. Non-use of pesticides and herbicides saves money on inputs, and eliminates risks from herbicide-resistant weeds, herbicide carryover in diversified crop rotations, and chemical impacts on water quality (Rodale, 2011a). Purchased organic fertilizers cost more per pound of nutrient than conventional soluble fertilizers, yet can pay for themselves when yields of high-value crops like broccoli respond to the input (Collins and Bary, 2017). In field crops, reduced total input expenditures and organic price premiums could result in competitive or higher net returns from organic (legume covers + manure) *versus* conventional (soluble fertilizer) systems (Delate, *et al.,* 2015b; Rodale, 2011a, 2015).

Concept #1: *USDA Organic Standards Require Long-term Investment in Soil Health*

The USDA National Organic Program (NOP) requires organic producers to use "tillage and cultivation practices that maintain or improve physical, chemical, and biological condition of soil, and minimize erosion," and to use cover crops and organic amendments to build SOM (USDA NOP Final Rule). In essence, NOP requires organic producers to make a long-term business investment in soil health, with up-front costs and risks, and economic benefits (yield stability, input efficiency) that may take years to accrue. For example, corn grain yield benefits from cover cropping increase after 4 consecutive years of the practice (USDA, SARE, 2016).

> NOP defines organic production as a system of practices that "foster cycling of resources, promote ecological balance, and conserve biodiversity." Toward this end, the Crop Rotation Standard requires organic farmers to "implement a crop rotation including . . . sod, cover crops, green manure crops, and catch crops that . . . maintain or improve soil organic matter, provide for pest management, manage deficient or excess plant nutrients, and provide erosion control" (USDA NOP Final Rule).

Concept #2: *Idle, bare soil is starving and at risk*

The long fallow periods in a typical corn-soy or vegetable rotation without winter cover crops subject the soil life to a protracted "fast" that can deplete populations of mycorrhizal fungi and other beneficial organisms (Kabir, 2018; Rillig, 2004; Six, *et al.,* 2006). In addition to increasing risks of erosion and depleting SOM (photo), prolonged bare fallows reduce efficacy of fertilizer inputs, and exacerbate leaching losses (Kabir, 2018, Rosolem, *et al.,* 2017). Growing cover crops during the off-season can sustain soil life, conserve nutrients, and reduce long-term risks to fertility. When planting schedules or moisture limitations make a living cover impractical, crop residues or organic mulch can reduce the adverse effects of fallow.

In perennial fruit production, maintaining a bare orchard floor through tillage or herbicides can cut SOM levels by ½ compared to perennial cover with periodic mowing (Lorenz and Lal, 2016). In an organic orchard in Utah, alleys in a birdsfoot trefoil living mulch substantially enhanced SOM, microbial activity, tree root growth, and tree N nutrition over tilled bare fallow, with intermediate levels of soil and crop health under applied organic mulch (Reeve, 2014).

Stop, Thief! Exposed soil is highly prone to wind and water erosion, which rob fertility by selectively removing organic matter and clays, along with their adsorbed nutrients and microbiota. Nature creates only about an inch of new soil every 500 years; thus soil loss is one of the worst risks a farmer might face. You don't have to see rills deep enough to twist an ankle to be losing soil. Watch for signs of sheet erosion, such as water-flow or wind-blow patterns on the soil surface, a smooth or "sealed" surface, or "perched stones".

Crop Rotation, Diversification, and Cover Crops

The USDA Natural Resources Conservation Service (NRCS) has developed four principles of soil health management:

- Keep the soil covered as much as practical.
- Maintain living roots in the soil.
- Build soil microbial diversity through crop diversity.
- Minimize soil disturbance.

Research into organic and sustainable agricultural systems has largely validated these principles (Schonbeck, *et al.,* 2017). Organic producers face significant challenges in putting these principles into practice, and can incur costs and risks doing so. However, extended fallow periods without living cover and the erosion that can ensue constitute some of the gravest risks that any farmer can face (see *Concept #2*).

The importance of crop rotation in protecting soil quality and reducing risks related to pests, weeds, and diseases is well documented (Mohler and Johnson, 2009). Diversified rotations can reduce risks of catastrophic financial losses when one crop fails, and have been shown to enhance yield and soil health in organic systems (Moncada and Sheaffer, 2010; Ponisio, *et al.,* 2014). Adding a perennial grass-legume sod phase (1 to 3 years) to the rotation can be especially effective in restoring SOM, tilth, and fertility, and reducing annual weed populations (Moncada and Sheaffer, 2010). In cash grain rotations, income foregone by rotating into perennial sod can sometimes be recovered in part by haying or grazing the sod. Rotationally-grazed livestock can also enhance the soil building effect.

Costs related to adding new crops to the rotation may include acquiring new skills, tools, and equipment. In addition, rotating into perennial sod phase to restore soil health in an intensive vegetable rotation could result in significant income foregone, and may not be practical for small-acreage market gardens. Diversifying cash crops requires careful market research and enterprise budgets to ensure that the expanded suite of crops is likely to maintain or improve net returns.

Cover cropping plays an essential role in soil health and fertility management in organic cropping systems (Hooks, *et al.,* 2015; Moncada and Sheaffer, 2010). For example, the roots of winter annual legume cover crops enhance both SOM and plant-available N (Hu, *et al.,* 2015). Deep rooted cover crops can penetrate hardpan and enhance rooting depth, moisture and nutrient acquisition, and yield by cash crops, such as corn or soybean after tillage radish, or cotton after winter rye (Gruver, *et al.,* 2016; Marshall, *et al.,* 2016; Rosolem, *et al.,* 2017).

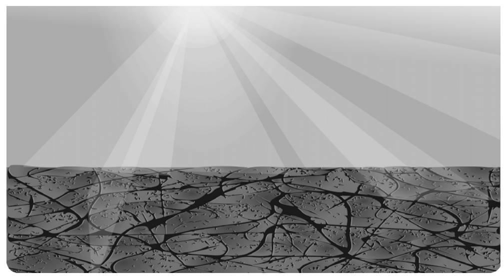
Yet, adding cover crops can entail new risks (Moncada and Sheaffer, 2010). In selecting and managing cover crops, the organic producer must consider costs of seed, planting, and termination, as well as the cover crop's effects on planting dates, soil moisture, and nutrient availability for the following crop. In drier regions, a high biomass cover crop may not leave sufficient moisture for optimum yield in a subsequent grain crop (Thompson, *et al.,* 2016). In colder regions with short growing seasons, cover crops can hurt yields by delaying planting or slowing N mineralization (Liebman, *et al.,* 2017; Moncada and Sheaffer, 2010).

Annual nationwide farmer surveys have shown that, on average, cover cropping slightly enhances corn, soybean, and wheat yields, especially in drought years (USDA SARE). Farmers cite soil health benefits, followed by yield stability and weed management as their leading motivations for cover cropping, and a growing number perceive a net economic advantage from the practice (USDA SARE, 2017). Challenges include identifying the best cover crop species, mixes, and management practices for the grower's site, climate, soils, and management system; and, for organic producers, managing the cover crop without herbicides. In a survey of New York farmers, most participants reported that cover cropping reduced costs for soil erosion repairs; nearly ½ saved money by reducing fertilizer inputs, and slightly more than ½ reported improved crop yields (Mason and Wolfe, 2018). In semiarid regions such as Montana, the Dakotas, and interior Washington and Oregon, cover cropping can play a vital role in maintaining soil health in grain rotations, yet cover crop species must be selected and managed with care to realize benefits and minimize yield tradeoffs (see *Concept #3*).

Concept #3: *Choosing and managing cover crops where rainfall is limited: not all "drought tolerant" cover crops conserve moisture*

Some drought tolerant cover crops are light users of soil moisture, and can be good choices for semiarid regions. These include barley, camelina, phacelia, medics, foxtail millet, pearl millet, amaranth, lablab, and pigeon pea (USDA ARS, 2018). However, the drought resilience of alfalfa, sainfoin, sunflower, rye, triticale, and tillage radish results from their deep, extensive root systems that consume large amounts of moisture throughout the soil profile. While alfalfa and perennial forage grasses can be excellent choices for soil building in moderate to high rainfall regions, their use during organic transition in semiarid regions like Montana can deplete moisture reserves throughout the soil profile, thus limiting subsequent crop yield for several years (Menalled, *et al.,* 2012).

In addition, the contrasting rainfall patterns of the Dakotas (mostly in summer) and the interior Pacific Northwest (mostly in winter) may require different cover crop species and strategies for these two regions (Michel, 2018). NRCS scientists worked with 20 farmers for 4 years in eastern Washington to determine the best cover crops to use *in lieu of* the traditional wheat/herbicide fallow rotation, known to deplete soil health. Cover crops planted in late spring (not in fall immediately after wheat harvest, when the soil is driest) performed best. Surprisingly, cowpea and sunnhemp, noted for their vigor and resilience to heat and drought in the southeastern U.S., did poorly in eastern Washington, whereas a cool season field pea (*Pisum sativum*) performed well as a N fixing rotation crop (Michel, 2018). Depending on soil moisture levels remaining after the cover crop, wheat yields varied from 20% higher to 60% lower than without cover; yet participant farmers remain eager to fine-tune the cover cropping practice to achieve both satisfactory yield and healthy soil.



Nutrients, Compost, Manure, and Crop-Livestock Integration

"Feed the soil, and let the soil feed the crop," is a founding principle of organic agriculture. While it provides a good starting point, it does not eliminate production risks related to deficient or excess nutrients, particularly nitrogen (N) and phosphorus (P). Organic crop yields are often limited by insufficient N, especially in soils recently transitioned from conventional to organic management, in which SOM, soil life, and N mineralizing capacity are initially below optimum. Increasing organic fertility inputs can help maintain yields, but may also incur risks (see *Concept #4*).

The NRCS Nutrient Management conservation practice standard (CPS 590) outlines the "four Rs" of nutrient management for crop yields and resource protection: right placement, right amount, right nutrient source, and right timing (USDA NRCS). However, because of the complex nature of biologically mediated nutrient cycling, nutrient release from manure, cover crops, and other organic nutrient sources can be difficult to predict and manage precisely, especially for N. As a result, organic systems can be challenged by crop N deficiencies, N surpluses subject to leaching, and sometimes both within the same growing season (Muramoto, *et al.,* 2015; Sullivan, *et al.,* 2017).

Finding the optimal N rate can be tricky for certain crops, such as broccoli and strawberry. In the Pacific Northwest and California, broccoli gave highly profitable yield responses to organic N fertilizers such as feather meal ($4–$10 per $1 on fertilizer) at rates up to 200 lb N/ac or more, yet harvest removed less than ½ this much N, with much of the balance leached to groundwater or converted into the potent greenhouse gas nitrous oxide (Collins and Bary, 2017; Li, *et al.,* 2009). In organic strawberry production, preplant applications of organic N from compost, cover crops, or broccoli residues are mineralized and leached months before the strawberry crop can utilize it (Muramoto, *et al.,* 2015). On the other hand, an organic lettuce trial in Colorado showed optimum yield and N use efficiency at just 25 lb/ac (Toonsiri, *et al.,* 2016). Because of the complex and site specific nature of N cycling, farmers may need to conduct simple trials to fine-tune fertilizer rates for best economic and soil health outcomes. For example, a Virginia organic farmer planted fall broccoli and cauliflower after a summer cover crop of pearl millet and cowpea was mowed and solarized for 2 days under clear plastic, and applied 0, 90 or 180 lb N per acre. The brassicas gave excellent yields after the cover crop alone, with no further response to added N (Anthony Flaccavento, 2015, personal communication).

Concept #4: *Nutrients and Compost: More is not Always Better*

Farmers often use a little extra compost fertilizer as "insurance" against yield losses to nutrient deficiencies, and soil test labs have historically recommended more N, P, and potassium (K) than crops actually utilize or remove through harvest. Similarly, organic producers often use compost liberally to ensure sustained yields from intensively-cropped systems such as high tunnels or small-acreage vegetable operations. This approach can lead to P surpluses in the soil.

Recent research has shown that crops may need much less fertilizer than recommended by soil tests, especially in biologically active soils that cycle nutrients effectively (Kabir, 2018, Kloot, 2018, Wander, 2015a). Vegetable harvests remove, 7–12 lb P (16–28 lb P_2O_5) and 64–93 lb K (77–112 lb K_2O) per acre (Sullivan, *et al.,* 2017; Wander, 2015a). Grain harvests may remove somewhat more P (25 lb/ac for a 150 bu/ac corn crop), but most of the K returns to the soil in stover, and only about 35 lb/ac is removed in the grain (Virginia Cooperative Extension). As little as 1 or 2 tons of compost or manure per acre can replenish the P, compost and legumes in the rotation replenish N, and many soils have large subsurface mineral reserves of K, from which deep rooted crops can replenish the topsoil. Even in the southeastern U.S. coastal plain where native fertility of the sandy soils is lo w, organically managed fields with good biological activity may show no crop response to added P and K, and little or no decline in P or K even when crops are produced without fertilizer (Kloot, 2018). However, failure to replenish nutrients removed in harvest over many years can eventually deplete the soil and lead to declining yields in organic crop production (Olson-Rutz, *et al.,* 2010).

Based on recent research findings, Oregon State Extension no longer recommends P or K applications for "high" soil test levels, and subtracts N credits for SOM mineralization, cover crops, and organic amendments to determine N recommendations (Sullivan, *et al.,* 2017).

While ensuring sufficient N for crop production is a risk management imperative for all farmers, providing more nutrients than needed can also pose risks, including:

- Increased cost for inputs.
- Increased nutrient losses, nutrient pollution of groundwater and surface waters.
- Reduced soil food web function; mycorrhizal fungi suppressed by high soil P.
- Reduced yield, delayed maturity (excess N on pepper and other fruiting vegetables).
- Reduced crop quality, increased blossom end rot or tip burn (excess N and K).
- Increased crop susceptibility to certain pests and diseases.
- Increased weed growth.
- Grass tetany in pastured livestock (excess K and low magnesium in forage).

Manure is an important nutrient source for many organic growers, but its use requires care to minimize food safety risks. NOP Standards require a 120 day interval between application of manure (raw, aged, or composted at <130 °F) and harvest of most organic food crops. In addition, the Food and Drug Administration (FDA) has recently implemented food safety regulations for all produce growers. Preliminary studies indicate that foodborne pathogens in soil decline to undetectable levels by 120 days after manure deposition by grazing livestock (Patterson, *et al.,* 2016), and FDA has accepted the NOP rule as an interim guideline pending additional research. The hypothesis that healthy, biologically active soil can speed the attenuation of human foodborne pathogens in manure requires verification, and is currently under investigation (Pires, 2017).

Integrating crop and livestock production within the same farming system and returning manure to the fields is an excellent and time-honored nutrient management strategy that can optimize nutrient cycling within the farm and minimize the need for purchased nutrient inputs. Crop-livestock operations that market fresh produce, must take special care to prevent contamination of produce from pasture runoff, dust (particulates) that may contain manure pathogens, and manure storage or composting operations.

Finished compost can be especially effective for building stable SOM, water holding capacity, and soil fertility (Lewandowski, 2002; Reeve and Creech, 2015). However, relying on compost or manure as the primary means to build SOM or meet crop N needs can build surpluses of P and other nutrients in the soil. Excessive soil P ("very high" on soil tests) inhibits the mycorrhizal symbioses so vital to soil health and crop nutrition (Rillig, 2004; Van Geel, *et al.,* 2017), and can threaten water quality (Osmond, *et al.,* 2014). Soils that have been "built up" with manure and compost often mineralize more N from the active organic matter than crops can utilize, and the excess leaches (Sullivan, *et al.,* 2017). Nutrient-rich organic amendments such as poultry litter can also intensify weed competition when application rates exceed crop needs (Cornell, 2005; Mohler, *et al.,* 2008).

Producers must also consider direct costs of purchasing and applying amendments. For example, in organic dryland wheat production in Utah, a single heavy application (22 tons dry weight per acre) of dairy manure/bedding compost doubled topsoil SOM and grain yields for 16 years after application, yet returns on the enhanced organic wheat harvest did not fully pay for the compost application (Reeve and Creech, 2015).

Other Organic Amendments

In some cases, purchased organic or natural mineral amendments can reduce risk by remedying acidic or alkaline pH, deficiencies in specific micro- or macro-nutrients, or other soil health concerns. However, today's farm input catalogues offer such a dizzying array of products that certain risks may arise in trying to sort out what is actually needed to optimize soil health and crop production (see *Concept #5*). The main risks include the costs of purchasing and applying materials that are not needed or not effective on a particular soil, and inadvertently using a material that NOP has not approved for organic production. Some of the most "tried and true" materials include:

- Rhizobium inoculants for legume seed. These are vital when the right species of rhizobia for the legume planted are not already present in the soil. At a cost of just a few dollars per acre, legume inoculants are often inexpensive insurance for effective N [fixation].
- Liquid fish and seaweed based fertilizers for in-line fertigation. Risks include problems with clogging drip systems, but a number of growers and researchers have used these materials successfully, realizing high nutrient use efficiency and low environmental risks (Toonsiri, *et al.,* 2016).
- Mycorrhizal fungal inoculants applied to root balls just before transplanting. Most often used for perennial stock, this practice can enhance establishment of fruit and nut crops in soils where the desired mycorrhizal symbionts are not already present.

Concept #5: *Navigating the Organic Input Smörgåsbord*

In addition to organic and natural mineral fertilizers and amendments, commercial vendors offer a large and growing plethora of other products claimed to enhance soil health and fertility, crop yield, or nutritional and market quality of produce. These include:

- Compost teas, bokashi, Effective Micro-organisms, Biodynamic preparations, and other microbial inoculants or biostimulants applied to soil, seeds, root balls, or foliage.
- Humic acids and humate products.
- Biochar.
- Rock powders and other natural mineral products with multiple trace elements.
- High calcium limestone, gypsum, and other minerals applied to achieve specific ratios of cations (Ca, Mg, K, Na) or other nutrient claimed to improve soil and crop health.

Many organic farmers use one or more of these products or methods, and consider them a vital part of their production and soil health management strategies. While most of these products are unlikely to harm soil, crops, or the environment, not all have been approved by NOP for organic production, and many lack scientific evidence that their benefits justify their purchase costs. Rigorous field evaluations of biochar, humates, and formulaic nutrient management systems such as the "base cation saturation ratio" (BCSR) have given mixed and often highly site-specific results. In other words, they may or may not work on your farm.

Considerable research has gone into the development of some of the newer mycorrhizal inoculants and other microbial products now commercially available. Yet, they often have little impact when applied to the soil (Kleinhenz, 2018), likely because the indigenous soil microbiota overwhelms the added inoculum. Mycorrhizal or other inoculants applied to seeds or root balls can improve crop performance in depleted soils, but may have no effect in healthy soils whose biota already perform the functions for which the inoculant has been selected.

Tips for avoiding unnecessary costs and risks when visiting the "inputs smörgåsbord":

- Beware sweeping claims that a given product can solve all your soil problems.
- Select a product with specific objectives in mind.
- Select a product whose development was based on sound research and field trials.
- Make sure the product is NOP-approved for organic production.
- Try the material on a small scale first, in a side by side comparison trial.

The Tillage Dilemma and Integrated Soil Health Strategies

Over the past 30 years, organic researchers and farmers have attempted to save soil through rotational no-till systems, in which high biomass cover crops are roll-crimped or mowed before no-till cash crop planting. These systems save fuel and labor on field operations, consistently enhance SOM and soil health, and—with optimum tools and management technique and favorable weather—can give excellent results (Rodale, 2011b). However, problems with crop establishment, weed pressure, and N limitation can reduce organic crop yields and net returns, especially in northern regions where the organic no-till system reduced corn and oat grain yields by 63% and soybean yields by 31% in multiple-site field trials (Barbercheck, *et al.,* 2008; Delate, 2013). In Missouri and the mid-Atlantic region, organic no-till soybean in roll-crimped rye gave full yields, while organic corn showed significant yield decreases when planted no-till in roll-crimped legume + rye covers (Barbercheck, *et al.,* 2014; Clark, 2016). In warm-temperate or tropical regions, vegetable crops gave similar yields for the full-till and rotational no-till systems (Delate, *et al.,* 2015a; Morse, *et al.,* 2007).

Several strategies for reducing tillage intensity in organic systems have been shown to protect soil quality while maintaining crop yields. For example, strip tillage speeds soil warming and N mineralization in the crop row while leaving alleys undisturbed and residue-covered, and shows promise for organic vegetable and row crop production (Caldwell and Maher, 2017; Rangarajan, 2018). Other promising approaches include using a spading machine *in lieu of* a plow-disk (Cogger, *et al.,* 2013), chisel plow *in lieu of* inversion (turn plow) (Zuber and Villamil, 2016), shallow (3″) tillage (Sun, *et al.,* 2016), ridge tillage (Williams, *et al.,* 2017), and sweep plow undercutter *in lieu of* disking to terminate cover crops (Wortman, *et al.,* 2016). Integrated organic weed management can reduce the number of cultivations needed, thereby protecting soil and reducing direct costs for field operations (Michigan State University, 2008).

Integrated soil health strategies that include diversified rotation, cover crops, compost or manure application, and practical measures to reduce tillage intensity often yield greater soil benefits and sometimes higher crop yields than any one of these practices alone (Cogger, *et al.,* 2013; Delate, *et al.,* 2015a; Wander, *et al.,* 2014). Long-term grain-forage farming systems trials have shown equal or greater SOM and soil microbial activity in integrated organic systems with routine tillage compared with conventional continuous no-till (Cavigelli, *et al.,* 2013; Wander, *et al.,* 1994). However, integrated systems can be more complex and costly to implement, and require greater management skills.

Soil Health in High Tunnels

High tunnels can be especially important for organic specialty crop growers in cold-temperate climates (season extension) or high rainfall climates (reduce disease in tomato, tree and vine fruit, *etc.*). However, the high tunnel environment presents unique challenges in co-managing production risk and soil health. Greater capital and labor investments in a small production area, and the opportunity for year-round production, impel producers to crop the high tunnel intensively, and to apply compost frequently to maintain SOM and fertility. Exclusion of natural rainfall results in net upward movement of soil moisture, which can accentuate accumulation of P, some other nutrients, and soluble salts in the topsoil. Visible salt accumulations (white surface deposit) and salinity-related yield or quality reductions can occur. Cover crops can play an especially vital role in restoring soil health and reducing reliance on compost and other organic amendments. Although rotating high tunnel space out of production foregoes substantial income in the short run, cover cropping may help sustain soil health and crop yield in the long run.

Organic Transition

Farmers undertaking the transition to organic production often encounter greater risks than established organic producers working fields with a history of organic management because:

- Newly organic farmers face a steep learning curve, especially with regard to nutrient, weed, and pest management without synthetic agrochemicals.
- Organic certification and higher prices for certified organic products are not available for the first 3 years on land transitioning from conventional to organic production.
- Newly-transitioning fields often have soil health problems such as low SOM, depleted soil life, depleted or excess nutrients, surface or subsurface compaction, and erosion.
- Soil microbes tend to consume N during the early stages of soil rebuilding, leaving less plant-available for crop production.
- Weeds, pests, and plant diseases can be difficult to manage during transition, especially if the previous crop rotation maintained low aboveground and soil biodiversity.
- As a result, crop yields may be substantially lower during transition, recovering in later years as the soil ecosystem adapts and responds to organic practices (Rodale, 2015).

It can be especially challenging for a beginning organic farmer to simultaneously acquire needed skills, restore soil health and ecological balance on land with conventional management history, and remain financially solvent during the transition period (Menalled, *et al.,* 2012). Established organic producers who are transitioning additional acreage have the advantage of experience, yet still have to be prepared for higher labor and other costs, soil health issues, and lower yields and market prices from crops in the new fields.

Results of several studies indicate that rotating fields into a multispecies perennial sod during the 3 year organic transition can be especially effective for restoring soil health and fertility, and reducing weed seed populations (Borrelli, *et al.,* 2011; Briar, *et al.,* 2011; Cardina, *et al.,* 2011; Eastman, *et al.,* 2008; Hulting, *et al.,* 2008; Rosa and Masiunas, 2008). Although taking the field out of production means foregoing income during the transition, management costs are also greatly reduced compared to battling weeds and "tired" soil to bring a demanding crop to market. This strategy may not be feasible for small-acreage operations unless producers have off-farm income or other financial resources to tide them over through the transition period.

Human Health, Environmental, and Regulatory Risks; USDA Programs and Resources

Organic producers may face several risks related to human and environmental health:

- Unintended contamination of organic crops with NOP-prohibited substances, resulting in loss of certification for certain crops, fields, or the entire farm.
- Potential exposure of food crops to pathogens in manure (discussed earlier), leading to risks of liability for customer health consequences, or state or Federal regulatory action.
- Nutrient or sediment pollution of ground or surface water leading to state or Federal regulatory action (organic practices generally reduce but do not eliminate this risk).

On the upside, the importance of soil health and benefits of organic systems are gaining wider recognition, and USDA agencies are offering more assistance and resources for organic and conservation-minded farmers and ranchers (see *Resources 1–13, 18a* and *18b* in the Information Resources section on pages 36–41). In addition to administering USDA organic certification, the National Organic Program (NOP) provides excellent resources for organic growers, including an Organic Certification Cost Share (*Resource 11*).

The USDA Risk Management Agency (RMA) now recognizes NRCS Conservation Practices for soil, water, air, plant, and animal resources as Good Farming Practices compatible with crop insurance eligibility, effective in 2017 and subsequent years (USDA RMA, 2016).

> Note: The use of NRCS Conservation Practices **may** be recognized by agricultural experts for the area as good farming practices; however, the use of NRCS Conservation Practices is not necessarily compatible with all crop insurance policies and should be discussed carefully with your insurance agent. This is particularly true if you are making sudden changes in farming p[r]actices. You must demonstrate that the new practices do not negatively impact the ability of the insured crops to make normal progress toward maturity and produce at least the yield used to determine the production guarantee or amount of insurance and provided. The NRCS Conservation Practice is not an uninsurable practice under the terms and conditions of the individual crop insurance policy.

RMA has worked with NRCS and the Farm Services Agency (FSA) to develop regional cover crop management guidelines for crop insurance eligibility (USDA NRCS, 2013). However, these guidelines still limit the flexibility of management decisions and could deter cover crop use, especially in lower-rainfall regions (Jeff Schahczenski, National Center for Appropriate Technology, personal communication, 2018). On the other hand, the most recent cover crop survey indicated that most crop insurance professionals now understand and support cover cropping (USDA, SARE, 2017). In addition, RMA now offers a Whole Farm Revenue Program (WFRP, *Resource 13*) that supports crop diversification (Schahczenski, 2018b).

NRCS working lands conservation programs provide financial and technical assistance to farmers to implement conservation measures, including cover crops, crop rotation, nutrient management, and other soil health practices (*Resources 4, 18a, 18b, 18c,* and *42c*). Conservation program payments can help defray the up-front costs of adopting new practices, and NRCS also provides extensive information resources online related to soil health and soil management.

Other valuable conservation practices include installation of windbreaks, hedgerows, riparian buffers, filter strips, and other conservation buffers. These buffers consist of woody or herbaceous perennial plantings strategically placed: to protect streams, other sensitive ecosystems, or cropland from runoff containing sediment, nutrients, or pesticides; to intercept pesticide drift and other airborne contaminants; to protect soil on highly erodible land; and/or to provide wildlife habitat. Buffer plantings can entail substantial capital investments in perennial stock that many farmers could not afford without NRCS cost share (*Resources 4* and *18b*). In addition to helping organic growers meet NOP standards regarding wildlife and biodiversity, buffer plantings can address several risks related to food safety and organic integrity as well as soil health:

- Soil losses from highly erodible lands.
- Nutrient or sediment pollution of on-farm or nearby water resources.
- Pesticide or genetically engineered (GMO) crop pollen drift into organic fields from neighboring non-organic farms.
- Pathogen-laden dust from on- or off-farm livestock and manure facilities.
- Fertilizer, pesticide, or manure runoff from neighboring farms.

Practical Tips for Reducing Risk Through Soil Health Management in Organic Systems

The first steps toward reducing risk in organic crop production are:

- Get to know your soil resources. Look up your location on the NRCS Web Soil Survey and identify the soil type, inherent properties, and potential constraints (drainage, slope, root-restrictive layers, *etc.*) for each field and pasture (*Resource 1* on page 36).
- Evaluate the current condition of the soil in each production area.
  - Obtain a soil test and compare with past season soil tests if available.
  - Observe and record the physical and biological condition of the soil (tilth, workability, earthworms, *etc.*).
  - Supplement with additional in-field or lab soil health measurements if desired.
- Review current practices and assess their potential impacts on soil health.
- Identify simple changes you can undertake to protect, restore, or improve soil organic matter, fertility, and soil health without incurring substantial costs or foregone income.

Use *worksheets 1* and *2* on pages 20–21 to help you conduct this initial assessment. Make a copy for each field, production area, or "map unit" on the soil survey. Answer each question, filling in relevant detail.

See the Resources section (pp. 36–41) for more on the science and practice of soil health and soil management, especially *Resources 1, 2, 3, 8, 14, 16, 17, 20, 23b, 29b, 31,* and *42f.*

Worksheet 1: Evaluate Yours Soil Resources

Farm Location: _______________ Date: _______________
Field No. and Description: _______________

NRCS Web Soil Survey	
Soil series and map unit	
Land capability class	
Other production constraints	
Soil Health Evaluation	
Are there visible signs of sheet, rill, or gully erosion?	
Is the topsoil soft, dark, crumbly, and easy to work, or hard and cloddy?	
Does the field drain well after rain, or does it remain wet, pond, or run off?	
Does the soil surface crust or seal readily after rainfall?	
Is there a subsurface hardpan that restricts rooting depth?	
Do you see evidence of abundant earthworms and other soil life?	

Do most crops thrive well with few pest, disease, or weed problems?	
Do crops stand well during dry spells, or do they soon become stressed?	
Do crops sustain yields and quality in dry, wet, and other difficult years?	
Do soil tests show an adequate and stable % SOM, or upward trend in SOM?	
Do soil test P and K reach optimum ("high") range, then level off?	
Do soil tests show buildup of excessive levels of P or other nutrients?	
Do soil tests indicate a drawdown of K or other nutrients below optimum?	
Have you conducted assessments, such as microbial respiration, active SOM, potentially mineralizable N, in-field soil health scorecards, or the Cornell Comprehensive Soil Health Assessment or other soil health evaluations? If so, summarize results here.	

Worksheet 2: Review Current Production Practices, Their Soil Health Impacts, and Next Steps To Improve Soil Condition and Reduce Risk

Consider your production system in the context of the soil assessment (*Worksheet 1*), note positive and negative impacts of current practices, and identify simple, low-risk modifications that can improve soil health or reduce risks, and can be implemented with current tools and resources at little additional cost. Examples include growing a cover crop during a long gap (fallow) in the rotation, leaving surface residues over winter *in lieu of* fall tillage, adjusting tillage implements to lessen soil impact, or adjusting nutrient inputs based on soil test results. More complex system changes will be considered in the following pages, including *Worksheet 3* for crop rotation changes.

Current Practices	Soil Health Impacts, Other Costs, Risks, and Benefits	Potential Low-Cost Solutions
Crop rotation, fallow periods:		
Cover cropping practices:		
Tillage tools, practices, and timing:		
Cultivation (tools, frequency) and other weed control tactics		
Organic amendments and nutrient (fertilizer) inputs		

The next steps toward effective co-management of soil health and production risks include adopting new or modified practices in three general areas:

- *Adding crops*—including cover crops, sod crops, and new cash crops or enterprises.
- *Reducing tillage*—frequency, intensity, depth, or percentage of field disturbed.
- *Adjusting inputs*—nutrients, organic matter, *etc.*

The long-term goal is to build or refine an integrated, sustainable, and profitable organic production system suited to your site. The rewards can include greatly improved soil health and water quality, increased crop resilience and yield stability, and a less risky, more profitable operation. However, adopting new practices can require gaining new knowledge, learning new skills, acquiring new capital equipment, and purchasing new seeds, amendments, or other supplies. Selecting the right suite of crops and practices for your climate, soil, and production system requires careful and informed decision making.

Tips:

- Take this process one step at a time. Adopting all the components of a new system at once can make for an impossibly steep learning curve, or capital investments in new tools that exceed the farm's financial capacity.
- Do a partial budget for each new practice you are considering. A partial budget estimates costs and benefits resulting from a specific practice or change in the operation. See *Resources 5* and *21c* for a partial budget for cover crops.
- Try a new crop, nutrient source, practice, or suite of practices on a small scale first.
- Do side-by-side trials to verify the crop yield or soil benefits of a new material or practice.
- Join a farmer network engaged in on-farm trials or information sharing. Some examples are listed in *Resources 23a, 24, 29c, 30,* and *31.*
- Utilize USDA programs that can help defray costs, reduce risks, or provide information and technical support. See *Resources 4, 11, 12 13, 18, 42a, 42b, 42c, 43,* and *45.*

Adding Crops

Adding a new crop to the rotation—whether annual or perennial, harvested for sale, grazed by on-farm livestock, or returned to the soil in its entirety—can address three of the four NRCS soil health principles: keep the soil covered, maintain living roots, and enhance biodiversity. A diversified rotation can confer long-term benefits to soil health, yield stability in cash crops, and net economic returns.

The simplest way to build crop diversity is to add a cover crop to the existing rotation. Successful cover cropping requires careful selection of species, seeding rates, and planting and termination dates and methods, based on the farm's climate, soils, production system, and rotation niches. Avoid cover crop pitfalls (see *Concept #6*) and optimize outcomes with a few basic steps:

- Identify your cover cropping goals.
- Identify the niches in your crop rotation into which a cover crop might fit.
- Note any cover cropping risks or constraints associated with your production crop mix, growing season, hardiness zone, rainfall patterns, soil types, and current soil condition.
- Utilize cover crop information and decision tools designed for your locale or region.
- Develop a partial budget for the cover crop, considering costs of seed, planting, and termination; savings on fertilizer or weed control; and expected soil and yield benefits. Partial budgeting tools provide research-based estimates of dollar value of these benefits.

Concept #6: *A few cover crop pitfalls to avoid and a few tips to reduce risks*

A thin, low-biomass, weedy cover crop can result from:

- Cover crop species not suited to climate and season, soil type, or farming system. *Nearby farmers or Extension can help you identify best cover crops for your locale and season.*
- Late planting (especially fall/winter cover crops).
- Low seeding rates.
- Old or poor-quality seed. *Buy fresh seed yearly (grasses, buckwheat, oilseeds) or every 2 years (legumes, crucifers).*
- Inadequate planting method. *Broadcast seed usually must be shallowly incorporated.*

Cover crops can interfere with production in certain circumstances:

- In regions with short growing seasons, it can be difficult to fit a cash and cover crop into the season, which means a difficult choice between terminating the cover crop early (low biomass, little benefit) and delaying cash crop planting (lower yield). Interseeding or overseeding cover crops into standing cash crops can help address this constraint.

- In drier regions, cover crops terminated too late (just before cash crop planting) can leave the soil profile too dry for crop establishment, thereby reducing yields. Select cover crops, planting, and termination dates to conserve moisture—see *Concept #3* on page 10.

Nutrient and weed management problems can arise when:

- Overmature cover crops self-seed. *Mow, roll, or till cover crops at late flowering.*
- Overmature or all-grass cover crops tie up soil N during subsequent cash crop.
- All-legume or crucifer cover crops release N too fast for the following crop to utilize, resulting in N leaching or de-nitrification. *Plant legume with cereal grain or other grass.*

Highly diversified cover crop mixes or cocktails have shown great promise in NRCS and on-farm trials from Pennsylvania to North Dakota, and elsewhere. However, cocktails can fall short of expectation when:

- Added costs of purchasing and blending seed of multiple crops exceed the added benefits compared to a single-species or two-species cover crop.
- Logistics of planting many different sizes and types of seed add to labor or equipment costs, or result in poor emergence of some species. *Build your cocktail gradually, add one new species at a time to the current cover crop on a trial basis.*
- One or two species in the mix dominate over the others, so that functions of the latter are lost. *Adjust seeding rates accordingly.*
- Different species mature at different times, which can make no-till termination (rolling or mowing) impossible, or lead to cover crop self-seeding.

Adding a perennial sod phase to your rotation can be an excellent long-term investment in soil health and yield stability when:

- Land resources are sufficient to make a living with some fields out of production.
- Sod provides grazing or hay for on-farm or nearby livestock operations.
- Yield improvements or cost savings from soil restoration compensate for the income foregone during the sod phase.

See *Concept #7* for a successful example of sod phase and crop-livestock integration.

Concept #7: *Elmwood Stock Farm: A Crop-Livestock Integrated System*

John Bell, Mac Stone, and Ann Bell Stone of Elmwood Stock Farm in Scott County, Kentucky (*http://elmwoodstockfarm.com/*) operate a 550 acre, diversified, certified-organic crop-livestock farm producing beef, pork, lamb, poultry, eggs, and mixed vegetables. Their rotations include:

- Corn-soybean-winter cereal (for their livestock); pasture seeded after grain in year 3 and managed for years 4–8 under multispecies, management-intensive rotational grazing.
- Three years of intensive vegetable production with tillage and cover crops, followed by 5 years pasture managed as above.
- Steeper areas are kept in permanent pasture.

Keys to the success of this operation:

- A long sod break allows the soil to recover fully. University of Kentucky found soil health in year 4 of the vegetable rotation, similar to the permanent pasture.
- Crop-livestock integration optimizes nutrient cycling and minimizes off farm inputs. The farmers bought only 200 lb organic fertilizers for the entire farm in 2016.
- Product diversity and quality, NOP certification, and best food safety practices ensure a loyal Community Supported Agriculture (CSA) membership and a profitable operation.

Based on a tour of Elmwood Stock Farm hosted by Ann and John Stone on January 26, 2017.

Another way to build the diversity of your rotation is to add one or more new production crops for sale, or to provide pasture, hay, or feed grains for an existing or new livestock enterprise. Enterprise diversification can reduce risk if the level of system complexity is manageable and practical. Farmers can "go under" as a result of trying to manage too many crops or enterprises at once, or launching a new enterprise or cropping system across the entire farm in one season. Suggested steps include:

- Evaluate your current enterprise mix, noting yields and net returns, risks, and soil health benefits and drawbacks for each crop or enterprise, and the overall farming system.
- Conduct a similar evaluation of the diversified enterprise mix under consideration
- Develop enterprise budgets for current and proposed new enterprises including:
  - Variable costs (seeds/starts, soil amendments, other inputs, labor, fuel, *etc.*).
  - Fixed costs (machinery and equipment, land use, *etc.*).
  - Gross income—historical data for current enterprises, best estimates for new ones.
- Try a new crop or livestock enterprise on a small area or small scale first, then expand it in future years if initial results are promising.
- Add one or two new components (cash crop, soil building crop, or livestock enterprise) at a time, and gradually build the functional diversity of your farming system.

Use *Worksheet 3* (page 26) to evaluate your current rotation, identify opportunities to reduce risk and build soil health by adding crops, and record changes implemented or trialed, and document outcomes. See examples on page 26.

For more on Adding Crops, see *Resources* section (pages 36–41), including:

- *Crop diversification, designing crop rotations: Resources 10, 22, 25, 27, 29a, 34, and 37.*
- *Cover crops, general: Resources 6, 7, 9, 15, 16c, 21, 25, 26, 27, 31, 32, 34, 39, 40, and 41.*
- *Relay interplanting cover crops into standing production crops: Resources 26 and 34.*
- *Cover crop selection tools: Resources 5, 21b, 26a, and 29a.*
- *Cover crops for dryland rotations in semiarid regions: Resources 36, 37, and 38.*
- *Economics of cover cropping: Resources 5, 19d, 21c, 26b, 26c, 30, and 33.*
- *Enterprise budgets and marketing for new enterprises: Resources 42e and 44.*
- *Crop-livestock integrated systems: Resources 29a and 30.*

Worksheet 3—Adding Crops for Soil Health, Profit, and Risk Reduction

Example 1: corn-soy rotation				
Current Rotation		**Concerns**	**New Crop**	**Implementation, Outcome, *Next Steps***
May–Sept.	Corn	Needs lot of N		
Oct.–May	Fall till, fallow	Erosion, N leaching	Rye cover	Plant 10/5, till 5/15, good biomass *Plant again next year, larger scale*

Worksheet 3—Adding Crops for Soil Health, Profit, and Risk Reduction—Continued

June–Oct.	Soybean			Some skips in stand, yield same, fewer weeds *Adjust planter for better seed soil contact.*
Nov.–Apr.	Fallow	Severe erosion	Vetch cover	Plant 11/2, poor biomass, weedy. *Interplant into soybean at 4-leaf stage.*
Example 2: intensive vegetable production				
Current Rotation		**Concerns**	**New Crop**	**Implementation, Outcome, *Next Steps***
Apr.–Oct.	Greens triple crop	Low residue, crusting	2 greens crops, then oats + peas	Plant cover 8/15 after summer greens harvest.
Nov.–Mar.	Fallow	Erosion		Less erosion, better tilth, but significant income foregone. *Harvest pea tips for market.*
Apr.–Aug.	Potato	Needs lot of N to yield		Higher yield, less response to added N. *Reduce feather meal rate.*
Sept.–Apr.	Oats + vetch cover	Thin stand, vetch hard seed, weedy	Rye + crimson clover	Seeded cover crop 9/1 Satisfactory cover crop stand and biomass.
May–Sept.	Summer vegies			Less weeding labor *Continue rye + clover before summer veg.*
Oct.–Feb.	Fall till, fallow	Erosion, N leaching	Rye + red clover thru year	Plant cover 10/1. Established well, but rotation now less profitable.
Mar.–July	Head brassicas	Low yield, soil depleted		*Try specialty grain for harvest (needs market research); expand rotation to 4 years with brassica after grain/red clover.*
Current Rotation *		**Concerns**	**New Crop**	**Implementation, Outcome, *Next Steps***
Approx. Dates	Crops Or Fallow			

* *Include all cash crops, cover crops, and fallow periods; note whether tilled or residue left on surface during fallows.*

Reducing Tillage

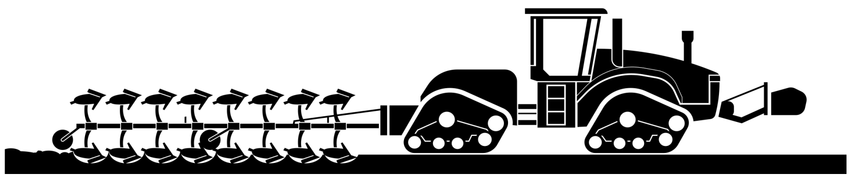
Look for opportunities to reduce tillage frequency and intensity in the cropping system. However, remember that it is not necessary to eliminate tillage. Strip tillage, in which a 4–12″ wide swath of soil is worked up to create a seedbed for each crop row, leaving alleys untilled, concentrates preplant soil disturbance in the crop row to promote soil warming, microbial activity and nutrient mineralization, and better seed-soil contact for prompt crop establishment. A large and growing number of tools for effective strip tillage, planting, and mechanical weed management have been developed that make strip tillage a viable option for many organic producers, especially when weed pressure is low to moderate.

In the event that high weed pressure, close row spacing for production crops, or other circumstances necessitate full-width tillage, several tools exist that do much less damage to soil structure than "conventional tillage" with moldboard plow, disk and/or rototiller. Examples include the rotary or reciprocating spader, power harrows that work the soil more shallowly and gently than the rototiller, and older, simpler tools such as chisel plow and field cultivator. These tillage methods reduce pulverization of soil aggregates, lessen damage to soil life, avoid inverting the soil profile, reduce risks of compaction and erosion, and thereby help maintain the soil health and resilience gained through cover cropping and other organic practices.

Cover crop-based rotational no-till is the most "advanced" conservation tillage option for annual crop rotations, and is both most promising for soil health and most risky for cash crop yields.

Rotational no-till is most likely to succeed and be economically viable:

- In warm climates with long growing seasons, in which slower N mineralization can be beneficial, and the cover crop has plenty of time to mature and attain high biomass.
- In sandy soils that drain and warm up quickly.
- Where weed pressure is light and dominated by annual species.
- On farms that already have the needed equipment, and farmers have past experience with no-till.
- When a strong N fixer like soybean or southern pea is sown into roll-crimped winter cereal grain cover, whose N tie-up slows weeds but not the legume production crop.
- In small-scale operations, in which opaque tarps or landscape fabric can be laid for 2–4 weeks over mowed or rolled cover before planting vegetable crops, to ensure full termination and weed control (Brust, 2014; Rangarajan, *et al.,* 2016)



Changes in tillage practices often require a significant capital investment in new tillage and cultivation equipment and tools. Opportunities for reducing tillage with less up front cost include:

- Adjusting current tools to work the soil more gently or shallowly, *e.g.,* slowing the PTO speed when operating rototiller or rotary harrow.
- Implementing or improving weed IPM to reduce need for cultivation.
- Cooperative purchase and sharing of a new tool.

For more on Reducing Tillage, see *Resources* section (pages 36–41), including:

- Organic conservation tillage, general: *Resources 7, 16d, 16e, 19,* and *41.*
- Roller-crimper and other no-till equipment: *19b, 39,* and *40.*
- Strip till equipment: *19a* (demo video), *39,* and *40.*
- Economic analysis of organic no-till: *19d.*
- Cover crop interseeding: *34.*

Adjusting Inputs

As noted earlier, organic growers can face risks related to either deficient or excessive plant-available nutrients, especially N and P. The historical lack of research data on crop responses to nutrients in organically managed soils has left organic producers with insufficient guidance to minimize these risks. Fortunately, with the growing understanding of the central role of soil health in crop nutrition, this is beginning to change. For example, Oregon State Extension recently updated its nutrient management guidelines for vegetable crops, taking a more conservative approach. N recommendations account for N from all sources (SOM, cover crops, compost and other amendments, irrigation water), and low or zero P and K recommendations are given when soil test levels are optimal (Sullivan, *et al.,* 2017).

Once the soil is healthy and soil test levels of P, K, and other nutrients test within optimum ("high") ranges, try to adjust inputs to maintain nutrient levels without building them any higher. Using compost or manure to meet crop N requirements will build soil P and possibly K, while legumes add N and organic matter without P or K. In addition, N from legumes costs \$2–\$3/lb, compared to \$5–\$6/lb N from organic fertilizers (Sullivan and Andrews, 2012). As noted earlier, N can be especially challenging to manage in a manner that both optimizes net returns and protects water quality and soil health.

Some nutrient related risk reduction tips include:

- Build overall soil health to reduce input needs for all nutrients.
  - Use living plants (cover, sod, and high residue cash crops) as the primary source of microbial food and soil fertility.
  - Use compost or manure sparingly as a supplement. These materials complement living plants in building soil health, and a little goes a long way.

- Use legume cover crops to provide N at a fraction of the cost of organic fertilizers.
- Ensure that any fertilizers or amendments are NOP-allowed before using them.
- Conduct side-by-side comparison trials to fine-tune N or other inputs.
  - Grow a crop with and without added N, or with different N rates.
  - Conduct trials for other nutrients and amendments.
  - Test microbial products, humates, biochar, and other products marketed for soil health in this way before investing in treating whole fields.
  - Conduct a partial budget analysis to estimate return on investment on for inputs.
- Provide plant-available N near crop roots to maximize utilization and minimize leaching.
  - Band-apply organic N fertilizer, or use in-row drip fertigation.
  - Use ridge or strip till to promote N mineralization near crop rows.
  - Plant legume or crucifer cover crop in future crop rows, and grass or grass-legume mix in alleys.
- Avoid over-irrigation in irrigated crops, which can leach N and reduce N use efficiency.
- For rice production, use the non-flooded System of Rice Intensification to improve crop and soil health, nutrient cycling, and yields (Thakur, *et al.,* 2016).
- Recycle nutrients within the farm to the greatest extent practical.
  - Crop-livestock integration can greatly reduce the need for NPK imports.
- Use crop foliar analysis to help identify actual needs for NPK and other nutrients.
- Test soil every 1–3 years to track nutrient trends and adjust inputs accordingly.
  - Use the same lab and take samples to the same depth and at the same season in successive sampling years.
- Adjust compost and manure rates according to current soil test P levels.
  - If soil P is low, apply these materials to meet crop N needs.
  - If soil P is high (optimal) apply at ~10 – 15 lb P/ac (= 22 – 35 lb P_2O_5/ac).
  - If soil P is very high (surplus) apply little or no compost or manure
- In high tunnel production, avoid or manage crop-limiting salt accumulations and nutrient excesses or imbalances.
  - Test soil once or twice a year, including soluble salts and nitrate-N.
  - Foliar analysis can be especially important in high tunnel nutrient management.
  - Use manure-based compost or fertilizer in moderation, based on soil test P levels.
  - Maintain SOM with plant-based compost or other low-nutrient organic materials.
  - Integrate legume cover or cash crops into high tunnel rotation to help meet N requirements, or use low-P organic N fertilizers.
  - To leach excess salts out of the topsoil, remove cover for a few months every few years to admit natural rainfall, or apply a heavy (4–6″) overhead irrigation.

For more on Adjusting Inputs, see *Resources* section (pages 36–41), including:

- Organic nutrient management, general: *Resources 8, 14, 16b, 17,* and *25.*
- Estimating plant-available N in over crops and organic fertilizers: *Resource 33.*
- Nutrient management for organic dryland grains: *Resources 35* and *36.*
- Nutrient management in high tunnels: *Resources 17e* and *42d.*

Managing Risk During Organic Transition

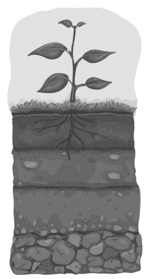
As noted before, the organic transition period can be especially risky. A few tips for mitigating this risk include:

- Transition one or a few fields at a time, keeping the majority of your acreage under its current management system to sustain farm income. In future years, transition more acreage as feasible until the entire farm is organic.
- Be sure to keep organic and non-organic production separate during harvest, post-harvest handling, and marketing.
- Consider rotating transition fields into perennial sod for 1, 2, or all 3 years if practical.

For more on managing risk during organic transition, see Resources section (pages 36–41), especially *Resources 25, 37, 42b,* and *43.*

Recent Research on Selected Topics in Soil Health and Risk Management

Crop diversification, soil health, organic crop yields, and production risks



The National Center for Appropriate Technology has conducted a nationwide farmer survey to compare production and market risks in diversified organic production systems *versus* conventional systems (Schahczenski, 2017). Preliminary findings indicate that organic producers spread their risk through crop diversification, reduce input costs by not using expensive GMO seeds and synthetic agro-chemicals, and having markets for productions with generally higher and perhaps more stable prices. They may reduce risk through cover cropping and other soil health management practices. A final report will be issued after survey analysis is completed.

Other research indicates that crop diversification can also reduce risk by building soil health directly (Kane, 2015). While organic and conventional rotations in the Rodale Institute long-term farming systems trials generated similar aboveground plant biomass, the more diverse organic rotations accrued higher active and total SOM and soil microbial activity (Wander, *et al.,* 1994). In addition, the average "yield gap" between organic and conventional crop production has been estimated at about 19%, but this figure diminishes to 8% when organic crops produced within a diversified crop rotation are compared to conventional crops in monoculture or low-diversity rotation (Ponisio, *et al.,* 2014).

Farmer Perceptions of Benefits and Risks Associated With Cover Cropping

Annual farmer surveys conducted by the SARE program since the 2012 growing season have documented a steady increase in the use of the practice, based on widespread perception of benefits to soil health, weed management, and crop yield stability. Survey respondents who use cover crops, planted an average of 217 acres per farm in cover crops in 2012, increasing to more than 400 acres in 2017 (USDA, SARE), citing soil health, weed management, and crop yield stability as their top three reasons for adopting or expanding the practice. Eighty-five percent reported observable improvements in soil health, 69% saw weed control benefits, ⅔ noted greater yield stability, and ⅓ realized greater net profits from cover cropping. While survey respondents who reported not using cover crops indicated that financial incentives (such as EQIP cost share under the Cover Crop conservation practice code 340) would increase the likelihood that they would adopt the practice in the future; those currently using cover crops consider financial incentives only a minor factor in their cover cropping decisions.

Average yield gains from cover cropping have been modest but consistent over the 5 years of the survey, and tend to increase with number of years of cover crop use. For example, cover cropping improved 2015 corn yields by an average of 3.4 bu/ac (1.9%), but farmers who had been cover cropping for 4 or more years saw a corn yield benefit of 8 bu/ac (4.5%). In the severe drought year of 2012, cover cropping conferred greater yield benefits to soybean (11.6%) and corn (9.6%) than in the more favorable seasons since then. This illustrates the yield stability benefits of this practice, an important risk management consideration.

In a survey of 182 farmers in New York State, respondents cited poor drainage (60%), soil compaction (60%) and soil erosion (40%) as leading constraints on production (Mason and Wolfe, 2018). Half of those who planted cover crops and/or reduced tillage reported yield improvements from these practices, while only 3% and 10% reported yield costs from cover crops and reduced tillage, respectively. Over 60% of farmers reported that both practices reduced soil erosion and flooding, and enhanced crop drought resilience. Some 83% of respondents who planted cover crops or reduced tillage saved erosion repair costs; 74% of those who reduced tillage reported savings on labor, fuel, and machinery; 47% of those who use cover crops have been able to reduce fertilizer inputs, and crop-livestock integrated farms used cover crops as forage.

Cover Crops In Moisture Limited Regions

Dryland grain producers in semiarid regions face a paradox, in that the traditional wheat-fallow rotation degrades soil quality, even under no-till management, while growing a cover crop or a production crop (lentil, pea, dry bean, sunflower, or cereal grain) *in lieu of* fallow maintains or enhances health (Engel, *et al.,* 2017; Halvorson, *et al.,* 2002; Miller, *et al.,* 2008). However, the short-term effects of a cover crop (*in lieu of* tilled or herbicide fallow) on the yield of the following grain crop depends on how the cover crop affects available soil moisture.

For example, two studies in south-central Nebraska gave contrasting results with dryland corn grown in rotation with winter wheat. In trials at two sites (Franklin and Clay Counties), planting a diverse cocktail of non-winter-hardy grasses, legumes, and crucifers into wheat stubble in August reduced soil moisture reserves by 1.5″ compared to leaving the field fallow after wheat harvest; as a result, non-irrigated corn grown the following year showed a 5–10 bu/ac yield loss after the cover crop (Thompson, *et al.,* 2016). On the other hand, a SARE-funded on-farm trial in Webster County documented 10% higher corn yields after diverse cover crop mixtures were planted in July of the preceding year after wheat harvest (Berns and Berns., 2012). The mixtures left soil moisture levels similar to wheat stubble alone, while single-species cover crops of soybean, sunflower, or radish significantly reduced soil moisture and did not affect corn yield.

A Western SARE funded on-farm project showed significant decreases in dryland wheat yields after cover crops in the northern Great Plains, resulting from water consumption and sometimes N consumption by the cover crop (Miller, 2016). Winter pea generally supports higher subsequent wheat yields than spring planted legumes, and terminating legume covers at bloom rather than pod stage reduces water consumption and improves wheat yield (Olson-Rutz, *et al.,* 2010). While only a minority of farmers in a Montana survey reported planting cover crops in dryland grain rotations, most who do plan to continue or expand cover crop use, cited long-term soil health as the main benefit (Jones, *et al.,* 2015). Survey respondents also noted the N contributions, forage value, and long-term net economic benefits of cover crops, and most often cited seed cost and water consumption as reasons to consider not planting cover crops.

In a series of on-farm trials (20 farms × 4 years) in interior Washington State, cover crop impacts on wheat yield varied from severe (65%) reductions to significant (10–22%) increases (Michel, 2018). The depth to available soil moisture (DtM) at the time of wheat planting appeared critical: when the cover crop had little effect on DtM, wheat yields were unaffected or improved; when the cover crop dried the top several inches of the soil profile, wheat crop establishment and yield suffered. Field pea planted with cereal grains in spring or summer gave better cover crop biomass and weed control than covers planted in fall after harvest of the preceding wheat crop, again because of moisture limitation in the latter scenario. In addition to total annual precipitation (9–13″ for the farms in this study), the seasonal distribution of moisture (mostly winter in Eastern Washington *vs.* mostly in summer in the Northern Great Plains) plays a key role in determining best cover crops, planting, and termination dates (Michel, 2018).

Plant Breeding and Genetics

Perhaps one of the greatest sources of risk in organic production is the relative lack of regionally adapted crop cultivars that are well suited to organic farming systems. Key traits for successful organic production include the capacity to emerge vigorously without chemical seed treatments, to utilize organic sources effectively, to outcompete weeds, and to withstand pests and pathogens (Lyon, 2018). A 2015 survey of 210 organic vegetable farmers in the Northeastern region, identified resilience to diseases, pests, heat, cold, and other stresses as top priorities for plant breeders (Hultengren, *et al.,* 2016). In addition, the project's working group of farmers, breeders, Extension personnel, and other stake holders noted:

> ***"Cultivars are most productive under the conditions for which they were bred. This central concept of plant breeding points to the need for Northeast growers to have regionally-adapted varieties that were bred to thrive in the Northeast, with the climate and pests unique to our region. Furthermore, cultivars bred under conventional management—aided by synthetic fertilizer, herbicides and pesticides—will likely not be as productive under organic management."***
>
> (Hultengren, *et al.,* 2016, page 26).

A meta-analysis of 115 studies comparing crop yields in organic *versus* conventional farming systems showed the greatest "yield gaps" in wheat, barley, rice, and corn—crops for which "Green Revolution" cultivars were developed to give maximal yields in high-input conventional systems (Ponisio, *et al.,* 2014). The authors recommended breeding crops "under organic conditions" to narrow the yield gap and reduce environmental costs of high yield agriculture.

Over the past 15 years, several farmer-scientist participatory plant breeding teams funded through the USDA Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) began to address the need for new crop cultivars better suited to organic systems. Some promising developments include:

- Highly N-efficient and N-fixing corn with enhanced drought tolerance, giving competitive grain yields of superior protein content and quality. Seeds are now available to farmers and scientists through licensing agreements (Goldstein, 2015, 2018).
- The Northern Organic Vegetable Improvement Collaborative (NOVIC) has released cultivars of snap pea, snow pea, and sweet corn ('Who Gets Kissed?') with excellent emergence from cold soil (Myers, *et al.,* 2014).
- Heritable traits related to crop vigor, canopy closure, and habit of growth in wheat and soybean correlate with weed competitiveness; one new food-grade soybean cultivar has been released (Orf, *et al.,* 2016; Place, *et al.,* 2011; Worthington, *et al.,* 2015).
- Tomato advanced breeding lines that combine excellent flavor with resistance to several major fungal diseases. The team is also exploring tomato genetics and soil management practices that enhance crop interaction with soil microbes that induce systemic resistance (ISR) to foliar pathogens (Hoagland, 2016; Myers, *et al.,* 2018).
- Carrot advanced breeding lines that combine weed competitive traits (seedling vigor, large tops, early canopy closure) with resistance to Alternaria leaf blight, a leading carrot disease (Simon, *et al.,* 2016a, 2016b, Turner, 2015).
- Cover crop (Austrian winter pea, crimson clover, hairy vetch) breeding trials in IA, MD, NC, ND, NY, WA, and WI addressing farmer-identified priorities: N fixation, early emergence, biomass, winter hardiness, and regional adaptation (Ackroyd, *et al.,* 2016, Mirsky, 2017).
- Extensive research confirms genetic regulation of plant root depth and architecture, and great potential to breed crops for larger, deeper root systems that build SOM, improve nutrient and moisture use efficiency, and potentially enhance yields (Kell, 2011).

Each of these plant breeding developments can contribute to soil health and risk reduction by facilitating profitable organic production, reducing nutrient and water input needs, enhancing organic matter inputs to the soil, or promoting beneficial plant-soil-microbe interactions.

Conclusion

The past 2 or 3 decades of research have validated what experienced farmers have known for centuries: healthy, living soils support resilient farming systems with greater yield stability in the face of unpredictable weather extremes and other stresses. In other words, managing for soil health reduces production and financial risks, and therefore constitutes good business management as well as environmental stewardship. Research further validates the NRCS four principles of soil health:

keep the soil covered, maintain living roots, increase diversity, and minimize disturbance.

While healthy soil in itself almost always reduces production risks, practices undertaken to build soil health can entail new challenges, costs, and sometimes risks. For example, efforts to maximize cover crop biomass and eliminate tillage in a rotation of annual crops can lead to yield tradeoffs, especially for organic producers who cannot resort to herbicides and soluble fertilizers to address weed pressure and nutrient limitations. However, a growing body of research outcomes, producer experience, and innovation by farmers, scientists, and agricultural engineers has built—and continues to build—a substantial toolbox for organic growers seeking to optimize soil health while reducing their production and financial risks.

This guide aims to provide the organic producer with an outline of the principles of soil health-based risk management, and a set of information resources and tools to help put these principles into practice. Because of the highly site-specific nature of best crop rotation, cover crops, tillage methods, and nutrient management in organic production, this guide cannot, and does not aspire to prescribe a formula for best soil-based risk management practices. Its goal is to equip farmers with the knowledge and tools needed to identify and implement the best suite of crops and practices to build healthy soils, reduce risks, and optimize net financial returns from their farming operations.

Information Resources and Decision Support Tools for Risk Reduction through Soil Health Management in Organic Farming

Nationwide Resources

1. **NRCS Web Soil Survey.** Click "Start WSS," enter your postal address, select the appropriate area on the aerial map, click on Soil Map, and use Soil Data Explorer to learn more about each of the Map Units within your farming operation. Once you have identified your soil types (series), you can review the Official Soil Series Descriptions (see menu on survey home page). *https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm*.
2. **Explore the Science of Soil Health.** NRCS video series. Dr. Robin Kloot interviews farmers and scientists explaining the science and practice of soil health practices. *https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/health/?cid=stelprdb1245890*.
3. **NRCS Webinar Archive. Science and Technology Training Library.** Includes cover cropping, nutrient management, and other practices that reduce risk through soil health improvement. *http://www.conservationwebinars.net/listArchivedWebinars*.
4. **NRCS working lands programs—Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP).** Provide financial assistance to farmers to implement conservation, including cover crops, rotations, and other soil health practices. EQIP offers an Organic Initiative to help organic and transitioning producers meet NOP conservation requirements. See full listing of NRCS programs at *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/*.
5. **Cover Crop Economic Decision Support Tool.** A spreadsheet-based online partial budgeting tool for cover crops, available through NRCS Missouri Soil Health[,] *http://www.nrcs.usda.gov/wps/portal/nrcs/main/mo/soils/health;* or NRCS Illinois Soil Health, *http://www.nrcs.usda.gov/wps/portal/nrcs/main/il/soils/health/*.
6. **USDA Cover Crop Chart.** Provides succinct information on cover crop life cycle, habit of growth, and water use intensity for 58 cover crop species. Up-

dated Feb 2018. *https://www.ars.usda.gov/plains-area/mandan-nd/ngprl/docs/cover-crop-chart/*.

7. **SARE Learning Center, Cover Crops Topic Room.** *https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops*.
8. ***Building Soils for Better Crops,*** **3rd ed., by Fred Magdoff and Harold van Es. 2009. Sustainable Agriculture research and Education (SARE).** *http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*.
9. ***Managing Cover Crop Profitably,*** **3rd edition, USDA Sustainable Agriculture Research and Education (SARE).** *http://www.sare.org/Learning-Center/Books*.
10. **Crop Rotation on Organic Farms: a Planning Manual.** Charles L. Mohler and Sue Ellen Johnson, editors. Developed by a panel of 12 experienced organic vegetable farmers in the Northeastern region, this manual illustrates their crop rotations and discusses principles and practices for developing rotations that are applicable anywhere. Published by SARE. *http://www.sare.org/Learning-Center/Books*.
11. **National Organic Program.** Provides detailed information about organic certification *https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program*, and **National Organic Certification Cost-Share Program** offers 75% cost share for certification expenses up to a payment of $750, *https://www.fsa.usda.gov/programs-and-services/occsp/index*.
12. **Food Safety Outreach Program (FSOP).** Offered by USDA, funds non-profit organizations to provide education and training to help small, diversified, and organic producers meet FDA produce safety requirements. *https://nifa.usda.gov/food-safety-outreach-program*. For more information on farmer resources developed with FSOP funds, visit *http://sustainableagriculture.net/publications/grassrootsguide/food-safety/food-safety-training-program/*.
13. **Whole Farm Revenue Protection.** A risk management product offered by USDA Risk Management Agency, "tailored for any farm with up to $8.5M in insured revenue, including farms with specialty or organic commodities (both crops and livestock), or those marketing to local, regional, farm-identity preserved, specialty, or direct markets." *https://www.rma.usda.gov/policies/wfrp.html*. Farm enterprise diversification is rewarded with premium discounts. For more on WFRP, see an updated (2018) primer published by ATTRA at *https://attra.ncat.org/attra-pub/download.php?id=595*.
14. **Soil and Fertility Management in Organic Farming Systems.** Extension website, Organic Resource Area. Articles and video clips cover sustainable organic nutrient budgeting and management including improved N efficiency and avoiding/managing P and K excesses. Several articles on role of soil organisms and soil health in enhancing nutrient efficiency and reducing crop disease risks. *http://articles.extension.org/pages/59460/soil-and-fertility-management-in-organic-farming-systems*.
15. **Cover Cropping in Organic Farming Systems.** Extension website, Organic Resource Area. Articles and video clips on cover crop selection and management for organic systems and during organic transition, including several on reduced till management. *http://articles.extension.org/pages/59454/cover-cropping-in-organic-farming-systems*.
16. ***Soil Health and Organic Farming:*** **a series of practical guides published by the Organic Farming Research Foundation** (OFRF, *http://ofrf.org/*), and webinars archived at *https://articles.extension.org/pages/25242/webinars-by-eorganic*. Topics include:
    a. *Building Organic Matter for Healthy Soils: An Overview.*
    b. *Nutrient Management for Crops, Soil, and the Environment.*
    c. *Cover crops: Selection and Management.*
    d. *Practical Conservation Tillage.*
    e. *Weed Management: An Ecological Approach.*
    f. *Water Management and Water Quality.*
    g. *Plant Genetics, Plant Breeding, and Variety Selection.*
17. **National Sustainable Agriculture Information Service** (aka ATTRA). Offers one-on-one consulting by phone or online ("Ask an Ag Expert" on home page), as well as many information resources available free or for nominal charge. *https://attra.ncat.org/*.

a. *Soils and Compost.* Info sheets and videos at *https://attra.ncat.org/soils.html*.

b. *Tipsheet: Assessing the Soil Resource for Beginning Organic Farmers, https://attra.ncat.org/attra-pub/summaries/summary.php?pub=529*.

c. *Marketing, Business, and Risk Management.* Info sheet and videos at *https://attra.ncat.org/marketing.html*.

d. *Water Quality, Conservation, Drought, and Irrigation.* Info sheets and videos, including role of soil health in drought resilience and water quality. *https://attra.ncat.org/water_quality.html*.

e. *High Tunnels in Urban Agriculture.* Includes nutrient and salt management tips. *https://attra.ncat.org/attra-pub/summaries/summary.php?pub=552*.

18. **National Sustainable Agriculture Coalition** (NSAC), *http://sustainableagriculture.net/*, is the lead policy advocacy organization for sustainable agriculture and food systems at the national level. In addition to giving farmers a voice on Capitol Hill during farm bill negotiations and within USDA in program implementation, NSAC offers producers information resources at *http://sustainableagriculture.net/publications/*, including:

a. *Growing Opportunity: A Guide to USDA Sustainable Farming Programs.* 2017. Summary information on USDA programs including loans and microloans, crop insurance, conservation, food safety, organic certification cost-share, and more.

b. *Grassroots Guide to Federal Farm and Food Programs.* Updated after each new farm bill reauthorization (approximately every 5 years).

c. *Farmers' Guide to the Conservation Stewardship Program.* Last updated 2016.

d. *Organic Farmers' Guide to the Conservation Reserve Program Field Border Buffer Initiative.* May, 2016.

e. *Food safety information, including special reports on* ***Understanding FDA's Rules for Produce Farms and Food Facilities*** *(August, 2016), and* ***Am I affected?*** (updated July, 2018). A flow chart to help the producer determine what the FDA rules require for their operation based on products sold and total annual sales.

Northeast Region Resources

19. **Reduced Tillage in Organic Systems Field Day Program Handbook.** Cornell University Cooperative Extension, July 31, 2018 at Cornell University Willsboro Research Farm, Willsboro NY. *https://rvpadmin.cce.cornell.edu/uploads/doc_699.pdf*

a. Excellent information resources on strip tillage, pp. 11–15.

b. Roller-crimper to terminate cover crops—pros, cons, trouble shooting, pp. 19–40.

c. Roles of soil life in nutrient cycling, soil structure, and effects of tillage pp. 41–59.

d. Cover crop-based organic rotational no-till, including economic analysis from Rodale Farming Systems Trials, pp. 61–107.

20. **New York Soil Health.** A joint program of New York Department of Agriculture, Cornell University, and NRCS has conducted a farmer survey on benefits and costs of soil health practices. Ongoing activities include innovative organic cropping systems, soil amendments, and developing a Soil Health Roadmap. *http://newyorksoilhealth.org*.

21. **Northeast Cover Crops Council.** *http://northeastcovercrops.com/*.

a. Information by state and cover crop type (grass, legume, broadleaf, mix).

b. Decision support tool to be released in the near future.

c. *Cover Cropping Costs and Benefits.* Jeffrey Sanders, U. Vermont, 2014, 2 pp. Partial budget for several cover crop species and management scenarios in New England. *http://northeastcovercrops.com/wp-content/uploads/2018/02/Cover-Cropping-Costs-and-Benefits.pdf*.

22. **Rodale Institute Farming Systems Trial.** Reports and summaries of soil health and fertility, crop yield and net economic returns in long-term (since 1981) comparison of organic crop-livestock, organic crop, and conventional

cash grain systems. *https://rodaleinstitute.org/our-work/farming-systems-trial/*.

23. **Northeast Organic Farming Association** (NOFA, *https://nofa.org/*), with state chapters in CT, MA, NJ, NY, RI, and VT, offers research-based, practical information on soil health management practices.
24. **Pennsylvania Association for Sustainable Agriculture** (PASA). Conducts farmer-driven research and farmer-farmer exchange on soil health practices and farm economic viability through its Soil Institute, *https://pasafarming.org/soil-institute/*. PASA received a 2018 Conservation Innovation Grant to continue and expand its Soil health Benchmark Study. *https://pasafarming.org/*.

North Central Region Resources

25. **Risk Management Guide for Organic Producers** (K. Moncada and C. Sheaffer, 2010, U. Minnesota, 300 pp). Chapters on soil health, soil fertility, crop rotation, and cover cropping for organic corn-soy-forage production in the North Central region. *http://organicriskmanagement.umn.edu/*.
26. **Midwest Cover Crop Council.** Treasure-trove of information on selecting, planting, and terminating cover crops, including species descriptions, state-specific information, organic no-till, and interplanting. *http://mccc.msu.edu/*.
    a. *Cover crop selector tools for vegetable and field crops. http://mccc.msu.edu/selector-tool/*.
    b. *Economics of Cover Crops,* James J. Hoorman, Ohio State U., 2015, 54 pp. *http://mccc.msu.edu/economics-cover-crops/*.
    c. Other economic analyses. *http://mccc.msu.edu/?s=economics*.
27. **Integrated Weed Management: Fine-tuning the System.** Michigan State University Extension, 2008. (131 pp). Excellent manual developed in collaboration with organic farmers, with farm case studies. *http://www.msuweeds.com/publications/extension-publications/iwm-fine-tuningthe-system-e-3065/*.
28. **Reduced Tillage in Organic Systems Field Day Program Handbook.** Cornell (see *item 3* in *Northeast Region*). Includes information for the North Central region.
29. **Land Stewardship Project.** Extensive practical information on soil health, sustainable farming, and risk management. *https://landstewardshipproject.org/*.
    a. *Cropping Systems Calculator.* Helps producers in MN and IL evaluate economics of alternative crop rotations up to 6 years, including cash and cover crops with grazing (crop-livestock integrated) options. *https://landstewardshipproject.org/stewardshipfood/chippewa10croppingsystemscalculator*.
    b. *Talking Smart Soil.* Podcasts of producers using soil health practices. *https://landstewardshipproject.org/lspsoilbuilders/talkingsmartsoil.*
    c. *Soil Builders Network.* Farmer stories on soil health, profits, and resiliency. *https://landstewardshipproject.org/stewardship-food/soilquality*.
30. **Practical Farmers of Iowa.** Conducts farmer-driven research into field crop production including cover crops. *https://www.practicalfarmers.org/*. Research findings at *https://www.practicalfarmers.org/member-priorities/cover-crops/*, include a Jan. 4, 2018 report on *Economic Impacts of Grazing Cover Crops in Cow-Calf Operations.*
31. **Midwest Organic and Sustainable Education Service (MOSES)** maintains an extensive resource page with fact sheets, videos, *etc.* on Soils, Cover Crops, and Systems. *https://mosesorganic.org/farming/farming-topics/soils-systems/*.

Western Region Resources

32. **Cover Crop (340) in Organic Systems Western States Implementation Guide.** Rex Dufour (National Center for Appropriate Technology); Sarah Brown, Ben Bowell and Carrie Sendak (Oregon Tilth); Mace Vaughan and Eric Mader (Xerces Society), 2013. Excellent information on cover crop selection, innovative mixes, planting, and termination methods for organic production in the Pacific Northwest and California. *https://attra.ncat.org/organic/*.

33. **Cover Crop and Organic Fertilizer Calculator.** Provides Excel calculators for maritime and inland regions to estimate costs and PAN for cover crops and amendments. Calculator for Hawaii in development. *http://smallfarms.oregonstate.edu/calculator*.
34. **Innovations Help Vegetable Growers Find that Cover Crop Niche.** Nick Andrews, Oregon State University,2016. *https://extension.oregonstate.edu/crop-production/vegetables/innovations-help-vegetable-growers-find-cover-crop-niche*. **Relay Seeding Cover Crops in Fall and Winter Harvested Vegetables.** Nick Andrews, 2014. *https://extension.oregonstate.edu/crop-production/vegetables/relay-seeding-cover-crops-fall-winter-harvested-vegetables*. Practical innovations for integrating cover crops into organic vegetable and strawberry production in the maritime Pacific region.
35. **Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon.** Sullivan, D.M., E. Peachey, A.L. Heinrich, and L.J. Brewer. 2017. *Oregon State Extension Bulletin* EM 9165. More conservative (cost-effective) nutrient recommendations than past Extension bulletins, extensive section on N management, and careful consideration of both risks and benefits of fertilizers and organic amendments. *https://catalog.extension.oregonstate.edu/topic/agriculture/soil-and-water*.
36. **Soil nutrient management on organic grain farms in Montana.** K. Olson-Rutz, C. Jones, and P. Miller. 2010. *Montana State University Extension Bulletin* EB0200, 16 pp. Research findings on best cover crop species, and management for organic dryland wheat; analysis of costs, benefits, and net returns for various cover crop, intercrop, and crop-livestock integrated organic production systems. *http://msuextension.org/publications/AgandNaturalResources/EB0200.pdf*.
37. **From Conventional to Organic Cropping: what to Expect During the Transition Years.** Menalled F., C. Jones, D. Buschena, and P. Miller. 2012. *Montana State University Extension MontGuide* MT200901AG Reviewed 3/12. Provides guidance for organic dryland grain growers in meeting economic, cropping system, nutrient, and weed management challenges during organic transition. *https://store.msuextension.org/*.
38. **Meeting the Challenges of Soil Health in Dryland Wheat.** Leslie Michel, Okanogan Conservation District. Onfarm research into cover crop choices (4 years, 20 farms) NRCS webinar October 9, 2018. Science and Technology Training Library, *http://www.conservationwebinars.net/listArchivedWebinars*.

Southern Region Resources

39. **Southern Cover Crop Conference,** July 18–19, 2016. Includes fact sheets and videos on cover crop selection and mixes, soil health and soil life benefits, equipment for no-till and strip till systems, economics of cover cropping, and more. *https://www.southernsare.org/Events/Southern-Cover-Crop-Conference*.
40. **Southern Cover Crop Council** is developing a regional information clearing house at *https://southerncovercrops.org*, which currently offers excellent practical information on cover crop planting and termination tools, and timing for the Southeast Coastal Plain. Additional information for other agroecoregions across the South is under development.
41. **Center for Environmental Farming Systems (CEFS),** *https://cefs.ncsu.edu/*, in Goldsboro, NC includes an organic research unit including cover crops, conservation till, and organic grains. *https://cefs.ncsu.edu/field-research/organic-research-unit/*.
42. **Carolina Farm Stewardship Association (CFSA).** Offers consulting, beginning farmer training and mentoring, and other services. *https://www.carolinafarmstewards.org/*.
    a. Food safety—Good Agricultural Practices (GAP consulting. Manuals and videos. *https://www.carolinafarmstewards.org/gaps-consulting/*.
    b. Organic Certification Consulting. Assistance with organic transition and NOP [paperwork]. *https://www.carolinafarmstewards.org/organic-certification-consulting-services/*.
    c. Conservation Activity Plan and enrollment in NRCS EQIP Organic Initiative. *https://www.carolinafarmstewards.org/cap-consulting-services/*.
    d. Sustainable High Tunnel Management Consulting *https://www.carolinafarmstewards.org/high-tunnel-consulting/*.

e. Organic enterprise budgets for ten leading vegetable crops. *https://www.carolinafarmstewards.org/enterprise-budgets/*.

f. *Expert Tips* monthly blog posts by CFSA staff. Topics include soil health assessment (Sept. 2018), on-farm conservation and NRCS programs (July 2018) organic weed management (June 2018), and more. Older posts available at link at bottom. *https://www.carolinafarmstewards.org/forgrowers/experttips/*.

43. **Organic Transition and Production Handbook,** compiled by Eric Soderholm, Farm Organic Transitions Coordinator, CFSA. Extensive information on organic certification and soil fertility and soil health management practices for the Carolinas. *https://www.carolinafarmstewards.org/organic-transition-handbook/*.

44. **Southern Sustainable Agriculture Working Group.** *https://www.ssawg.org/*. Offers on line courses that can help producers assess business management risks: *Growing Farm Profits, https://www.ssawg.org/growing-farm-profits/*, and *Choosing Your Markets, https://www.ssawg.org/choosing-your-markets/*.

45. **Florida Organic Growers (FOG),** *http://www.foginfo.org/*, hosts Quality Certification Services for USDA organic, *http://www.foginfo.org/our-programs/certification/*.

References

Ackroyd, V.J., L. Kissing-Kucek, and S.B. Mirsky. 2018. *Northeast Cover Crop Efforts. http://mccc.msu.edu/wp-content/uploads/2016/11/MCCC2016_Northeast-Cover-Crop-Efforts.pdf*.

Baker, B., 2016. *Soil Microbial Interactions and Organic Farming.* Organic Farming Research Foundation. 8 pp. *https://ofrf.org/research*.

Barbercheck, M.E., W. Curran, J. Harper, R. Hoover, D. Voight, and G. Hostetter. 2014. *Improving Weed and Insect Management in Organic Reduced-Tillage Cropping Systems.* Final report on OREI project 2010–03391. CRIS Abstracts.*

Barbercheck, M.E., D.A. Mortensen, H. Karsten, E.S. Sanchez, S.W. Duiker, J.A. Hyde, and N.E. Kiernan. 2008. *Organic Weed Management: Balancing Pest Management and Soil Quality in a Transitional System.* Final report on ORG project 2003–04619. CRIS Abstracts.*

Berns, K., and B. Berns. 2012. *Dryland Cover Cropping Boosts Yields.* NC–SARE Producer grant FNC07–653. *https://www.sare.org/Learning-Center/From-the-Field/North-Central-SARE-From-the-Field/Dryland-Cover-Cropping-Boosts-Yields*. Full project report at *https://projects.sare.org/sare_project/FNC07-653/*.

Borrelli, K., R. Koenig, I. Burke, E. Fuerst and R. Gallagher. 2011. *Nitrogen Dynamics in Nine Rotation Systems from Transition to Certification of Organic Dryland Grain Production.* ASA Annual Meeting. *https://a-c-s.confex.com/crops/2011am/webprogram/Paper66429.html*.

Briar, S.S., S.A. Miller, D. Stinner, M.D. Kleinhenz, and P.S. Grewal. 2011. *Effect of Organic Transition Strategies for Peri-Urban Vegetable Production on Soil Properties, Nematode Community and Tomato Yield.* APPLIED SOIL ECOLOGY 47: 84–91.

Brust, G. 2014. *Organic Weed Control in No-Till Systems. https://extension.umd.edu/sites/default/files/_docs/articles/OrganicWeed-ControlUsingNo-till_3-2014_0.pdf*.

Caldwell, B. , and R. Maher. 2017. *Mulch for organic vegetables—grown in place.* Cornell Small Farms Program. *http://smallfarms.cornell.edu/2017/07/03/mulch-for-organic-vegetables-grown-in-place/*.

Caldwell, B., C.L. Mohler, Q.M. Ketterings, and A. DiTommaso. 2012. *Crop Yields During and After Transition in the Cornell Organic Grain Cropping Systems Experiment.* In: NORTHEAST ORGANIC RESEARCH SYMPOSIUM PROCEEDINGS, January 19–20, 2012, Saratoga Springs, NY, pp. 12–13.

Cardina, J., J. Felix, D. Doohan, D. Stinner, D, and M. Batte. 2011. *Transition Strategies that Control Perennial Weeds and Build Soil.* Final report on OREI project 2006–02014. CRIS Abstracts.*

Cavigelli, M.A., J.R. Teasdale, and J.T. Spargo. 2013. *Increasing Crop Rotation Diversity Improves Agronomic, Economic, and Environmental Performance of Organic Grain Cropping Systems at the USDA–ARS Beltsville Farming Systems Project.* CROP MANAGEMENT 12(1) Symposium Proceedings: USDA Organic Farming Systems Research Conference. *https://dl.sciencesocieties.org/publications/cm/tocs/12/1*.

Clark, K. 2016. *Organic weed management systems for Missouri.* Proposal and progress report on OREI project 2014–05341. CRIS Abstracts.*

Cogger, C.G., M. Ostrom, K. Painter, A. Kennedy, A. Fortuna, R. Alldredge, A.; Bary, T. Miller, D. Collins, J. Goldberger, A. Antonelli, and B. Cha. 2013. *Designing Production Strategies for Stewardship and Profits On Fresh Market Organic Farms.* Final report for OREI project 2008–01247. CRIS Abstracts.*

Collins, D.P. and A. Bary. 2017. *Optimizing nitrogen management on organic and biologically intensive farms.* PROCEEDINGS OF THE SPECIAL SYMPOSIUM ON ORGANIC AGRICULTURE SOIL HEALTH RESEARCH AT THE TRI-SOCIETIES ANNUAL MEETING, Tampa, FL, October 22–25, 2017. *http://articles.extension.org/pages/74555/live-broadcast:-organic-soil-health-research-special-session-at-the-tri-societies-conference*.

Cornell University, 2005. *Organic Cropping Systems Project: Compost Experiment.* Protocol at *http://www.hort.cornell.edu/extension/organic/ocs/compost/index.html;* results summary at *http://www.hort.cornell.edu/extension/organic/ocs/compost/pdfs/20042005results.pdf*.

Delate, K. 2013. *Developing Carbon-Positive Organic Systems through Reduced Tillage and Cover Crop Intensive Crop Rotation Schemes.* Final report for ORG project 2008–01284. CRIS Abstracts.*

Delate, K., C. Cambardella, and C. Chase. 2015a. *Effects of cover crops, soil amendments, and reduced tillage on Carbon Sequestration and Soil Health in a Long Term Vegetable System.* Final report for ORG project 2010–03956. CRIS Abstracts*

Delate, K., C. Cambardella, C. Chase, and R. Turnbull. 2015b. *A review of long-term organic comparison trials in the U.S.* SUSTAINABLE AGRICULTURAL RESEARCH 4(3): 5–14.

Eastman, C.E., M. Bazik, M., D.A. Cavanaugh-Grant, L.R. Cooperband, D.M. Eastburn, J.B. Masiunas, J.T. Shaw, and M.M. Wander. 2008. *Cropping Systems and Organic Amendments in Transitioning Farming Systems: Effects on Soil Fertility, Weeds, Diseases, and Insects.* Final report on ORG project 2003–04618. CRIS Abstracts.*

Egel., D., L. Hoagland, and A.K. Jaiswal. 2018. *Organic Tomato Foliar Pathogen IPM Webinar. http://articles.extension.org/pages/74594/organic-tomato-foliar-pathogen-ipm-webinar*.

Engel, R.E., P.R. Miller, B.G. McConkey, and R. Wallander. 2017. *Soil Organic Carbon Changes to Increasing Cropping Intensity and No-Till in a Semiarid Climate.* SOIL SCI. SOC. AM. J. 81(2): 404–413

Goldstein, W. 2015. *Breeding corn for organic farmers with improved N efficiency/N fixation, and protein quality.* PROCEEDINGS OF THE ORGANIC AGRICULTURE RESEARCH SYMPOSIUM, LaCrosse, WI February 25–26, 2015. *http://eorganic.info/node/12972*.

Goldstein, W. 2018. *High Methionine, N Efficient Field Corn from the Mandarin Institute/Nokomis Gold Seed Co.* PROCEEDINGS OF THE 9TH ORGANIC SEED GROWERS CONFERENCE, Feb. 14–17, 2018, Corvallis OR, pp. 25–26. *wgoldstein@mandaamin.org*.

Gruver, J., R.R. Weil, C. White, and Y. Lawley. *2016 Radishes A New Cover Crop for Organic Farming Systems. http://articles.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farming-systems*.

Halvorson, A.D., B.J. Wienhold, and A.L. Black. 2002. *Tillage, nitrogen, and cropping system effects on soil carbon sequestration.* SOIL SCI. SOC. AM. J. 66(3): 906–912.

Hamel, C. 2004. *Impact of arbuscular mycorrhizal fungi on N and P cycling in the root zone.* CAN. J. SOIL SCI. 84(4): 383–395.

Hoagland, L.A. 2016. *Practical approach to controlling foliar pathogens in organic tomato production through participatory breeding and integrated pest management.* Progress report for OREI project 2014–05405. CRIS Abstracts.*

Hooks, C., A. Leslie, and G. Chen. 2016. *Managing weeds in vegetables organically.* University of Maryland Cooperative Extension, 18 pp. *https://extension.umd.edu/sites/default/files/_images/programs/mdvegetables/OrganicWeedMgntVeg21May2016(1).pdf*.

Hooks, C. R., K. H. Wang, G. Brust, and S. Mathew. 2015. *Using Winter Cover Crops to Enhance the Organic Vegetable Industry in the Mid-Atlantic Region.* Final report for OREI project 2010–01954. CRIS Abstracts.*

Hu, S., S. Hu, W. Shi, A. Meijer, and G. Reddy 2015. *Evaluating the Potential of Winter Cover Crops for Carbon Sequestration in Degraded Soils Transitioning to Organic Production.* Project proposal and final report for ORG project 2010–04008. CRIS Abstracts.*

Hultengren, R., M. Glos, and M. Mazourek. 2016. *Breeding Research and Education Needs Assessment for Organic Vegetable Growers in the Northeast.* (Dataset). eCommons Digital Repository at Cornell University, 35 pp. *http://hdl.handle.net/1813/44636* or *http://blog.seedalliance.org/2016/10/03/reports-describe-plant-breeding-priorities-for-organic/*.

Hulting, A.G., D.A. Mortensen, and M. Barbercheck. 2008. *Fate of weed seedbank pools during the transition to an organic feed grain crop rotation in Pennsylvania.* WEED SCIENCE SOCIETY OF AMERICA 2008 PROCEEDINGS, Presentation No. 293.

International Panel on Climate Change (IPCC). 2014. *Climate Change 2014. Impacts, Vulnerability, and Adaptation. Report for Policy Makers.* 34 pp. *http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf*.

Jerkins, D. and J. Ory. 2016. *2016 National Organic Research Agenda: outcomes and recommendations from the 2015 National Organic Farmer Survey and Listening Sessions.* Organic Farming Research Foundation (*www.ofrf.org*), 126 pp.

Jones, C., R. Kurnick, P. Miller, K. Olson-Rutz, and C. Zabinski. *2015 Montana Cover Crop Survey Results.* Dept. of Land Resources and Environmental Sciences, Montana State University. 15 pp.

Kabir, Z. 2018. *Rethinking the nutrient management paradigm for soil health.* NRCS webinar, August 14, 2018. Science and Technology Training Library. *http://www.conservationwebinars.net/listArchivedWebinars.*

Kane, D. 2015. *Carbon sequestration potential on agricultural lands: a review of current science and available practices.* Breakthrough Strategies and Solutions and National Sustainable Agriculture Coalition. 35 pp. *http://sustainableagriculture.net.publications.*

Kell, D.B. 2011. *Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration.* Ann. Bot. 108(3): 407–418.

Kirschbaum, M.U.F. 1995. *The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage.* Soil Biology and Biochemistry. 27(6): 753–760.

Kleinhenz, M. 2018. *Assessing the Influence of Microbe-containing Crop Biostimulants on Vegetable Crops and Farms through On-station and On-farm Study.* Presentation at Annual Meetings of the American Society for Horticultural Science; Aug. 1, 2018; Washington, D.C. Available from Dr. Kleinhenz, *kleinhenz.1@osu.edu.*

Kloot, Robin. 2018. *Using adaptive nutrient management to answer "how much fertilizer do you actually need?"* NRCS webinar May 8, 2018. Science and Technology Training Library. *http://www.conservationwebinars.net/listArchivedWebinars.*

Lewandowski, A. 2002. Organic Matter Management. *https://www.extension.umn.edu/agriculture/soils/soil-properties/soil-management-series/organic-matter-management/.*

Li, C., Salas, W. and Muramoto, J. 2009. *Process Based Models for Optimizing N Management in California Cropping Systems: Application of DNDC Model for nutrient management for organic broccoli production.* Conference proceedings 2009 California Soil and Plant Conference, 92–98. Feb. 2009. *http://ucanr.edu/sites/calasa/files/319.pdf.*

Liebman, A., S. Perrone, T. Sooksa-nguan, and J. Grossman. 2017. *Linked Crop Production and Soil Organic Matter Impacts of Winter Annual Legumes in Upper Midwest Organic Agroecosystems.* Poster Number 1522, Tri-Societies Meetings, Tampa, FL, October 22–25, 2017. *https://scisoc.confex.com/crops/2017am/webprogram/start.html.*

Lorenz, K., and R. Lal. 2016. *Environmental Impact of Organic Agriculture.* Advances in Agronomy 139: 99–152.

Lyon, A. 2018. *Facilitating Farmer Collaboration in On-farm Variety Trials: Lessons from Wisconsin and British Columbia.* Proceedings of the 9th Organic Seed Growers Conference, Feb. 14–17, 2018, Corvallis OR, pp 21–22.

Magdoff, F. and van Es, H. 2009. *Building Soils for Better crops,* 3rd ed. Sustainable Agriculture research and Education (SARE). *http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition.*

Marshall, M.W., P. Williams, A. Mirzakhani Nafchi, J.M. Maja, J. Payero, J. Mueller, and A. Khalilian. 2016. *Influence of Tillage and Deep Rooted Cool Season Cover Crops on Soil Properties, Pests, and Yield Responses in Cotton.* Open Journal of Soil Science, 6, 149–158. http://dx.doi.org/10.4236/ojss.2016.610015

Mason, C.W., and D.W. Wolfe. 2018. *Survey of Costs, Constraints, and Benefits of Soil Health in New York: Initial Report and Summary. Reduced Tillage in Organic Systems Field Day Program Handbook,* July 31, 2018, Cornell University Willsboro Research Farm, Willsboro NY, pp. 8–9. *https://rvpadmin.cce.cornell.edu/uploads/doc_699.pdf.*

Menalled F., C. Jones, D. Buschena, and P. Miller. 2012. *From Conventional to Organic Cropping: What to Expect During the Transition Years.* Montana State University Extension MontGuide MT200901AG Reviewed 3/12. https://store.msuextension.org/

Michel, L. 2018. *Meeting the Challenges of Soil Health in Dryland Wheat.* NRCS webinar October 9, 2018. Science and Technology Training Library, *http://www.conservationwebinars.net/listArchivedWebinars.*

Michigan State University Extension, 2008. *Integrated Weed Management: Fine-tuning the System,* (131 pp.). *http://www.msuweeds.com/publications/extension-publications/iwm-fine-tuningthe-system-e-3065/.*

Miller, P., 2016. *Using cover crop mixtures to improve soil health in low rainfall areas of the northern plains.* Final report for Western SARE project SW11–099, 40 pp. *http://landresources.montana.edu/soilfertility/documents/PDF/reports/CCMFinal-RptSW11-099Apr2016.pdf.*

Miller, P.R., D.E. Buschena, C.A. Jones, B.D. Maxwell, R.E. Engel, F. Menalled, and B.J. Jacobsen. 2008. *Organic Production in the Challenging Environment of the Northern Great Plains: from Transition to Sustainability.* Proposal and 2008 progress report for ORG project 2005–04477. CRIS Abstracts.*

Mirsky, S.B. 2017. *Creating the Cover Crops that Organic Farmers Need: Delivering Regionally Adapted Varieties Across America.* Proposal and annual report for OREI project 2015–07406. CRIS Abstracts.*

Mohler, C., T. Bjorkman, and A. DiTommaso. 2008. *Control of weed size by compost application rate in an organic cropping system.* Weed Science Society of America 2008 Proceedings, Presentation No. 261.

Mohler, C.A. and S.E. Johnson. 2009. *Crop Rotations on Organic Farms.* Sustainable Agriculture research and Education (SARE) and Natural Resource, Agriculture and Engineering Service (NRAES). 156 pp. *http://www.sare.org/Learning-Center/Books.*

Moncada, K., and C. Sheaffer, 2010. *Risk Management Guide for Organic Producers.* U. Minnesota. 300 pp. *Chapter 13, Winter Cover Crops. http://organicriskmanagement.umn.edu/.*

Morse, R.D., H.L. Warren, M. Schonbeck, J.C. Diaz, J. Ruberson, and S. Phatak. 2007. *Integrating No-tillage with Farmscaping and Crop Rotations to Improve Pest Management and Soil Quality in Organic Vegetable Production.* Final report for ORG project 2003–04625. CRIS Abstracts.*

Muramoto, J., C. Shennan, and J., M. Gaskell. 2015. *Nitrogen management in organic strawberries: challenges and approaches.* (Webinar) *http://articles.extension.org/pages/73279/nitrogen-management-in-organic-strawberries:-challenges-and-approaches.*

Myers, J.R., M. Mazourek, E. Silva, and M. Colley. 2014. *Northern Vegetable Improvement Collaborative.* Final report on OREI project 2010–03392. CRIS Abstracts.*

Myers, J., J. Zystro, T. Hodge, and J. Dawson. 2018. *Taking Tomatoes Totally Organic.* Proceedings of the 9th Organic Seed Growers Conference, February 14–17, 2018, Corvallis, OR, pp 32–39.

Olson-Rutz, K., C. Jones, and P. Miller. 2010. *Soil nutrient management on organic grain farms in Montana.* Montana State University Extension Bulletin EB0200, 16 pp. *http://msuextension.org/publications/AgandNaturalResources/EB0200.pdf.*

Orf, J.H., T.E. Michaels, M.J. Sadowsky, and C.C. Sheaffer. 2016. *Improving soybean and dry bean varieties and Rhizobium strains for organic systems.* Final report on OREI project 2011–01942. CRIS Abstracts.*

Osmond, D.L., J.M. Grossman, G. Jennings, G.D. Hoyt, M. Reyes, and D. Line. 2014. *Water Quality Evaluation of Long Term Organic and Conventional Vegetable Production under Conservation and Conventional Tillage.* Final report on ORG project 2009–05488. CRIS Abstracts.*

Patterson, L., N. Navarro-Gonzales, M. Jay-Russell, and A. Pires. 2016. *Evaluating the Persistence of* ***Escherichia coli*** *in the Soil of an Organic Mixed Crop-Livestock Farm.* Proceedings of the 2016 Organic Agriculture Research Symposium.

Pires, A.F.A., P.D. Millner, J. Baron, and M.T. Jay-Russell. 2017. *Assessment of Current Practices of Organic Farmers Regarding Biological Soil Amendments of Animal Origin in a Multi-regional U.S. Study.* Food Protection Trends 38(5): 347–362.

Place, G.T., S.C. Reberg-Horton, D.A. Dickey and T.E. Carter. 2011. *Identifying soybean traits of interest for weed competition.* Crop Science 51: 2642–2654.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2014. *Diversification practices reduce organic to conventional yield gap.* Proc. R. Soc. B. 282, 20141396.

Rangarajan, A. 2018. *Strip Tillage,* video on Zone Tillage, Cornell Small Farms Program. *http://smallfarms.cornell.edu/projects/reduced-tillage/strip-tillage/.*

Rangarajan, A., M.T. McGrath, D, Brainard, Z.I. Szendrei, M. Hutton, E. Gallandt, M. Hutchinson, and B.J. Rickard. 2016. *Farmer Designed Systems to Reduce Tillage in Organic Vegetables.* Proposal and progress report for OREI project 2014–05381. CRIS Abstracts.*

Reeve., J. 2014. *Organic Stone Fruit Production: Optimizing Water Use, Fertility, Pest Management, Fruit Quality and Economics.* Final report for OREI project 2009–01338, CRIS Abstracts.*

Reeve, J., and E. Creech. 2015. *Compost Carryover Effects on Soil Quality and Productivity in Organic Dryland Wheat. http://articles.extension.org/pages/73247/compost-carryover-effects-on-soil-quality-and-productivity-in-organic-dryland-wheat.*

Rillig, M.C. 2004. *Arbuscular mycorrhizae, glomalin, and soil aggregation.* Can. J. Soil Sci. 84(4): 355–363.

Rodale Institute. 2011a. *The farming systems trial: celebrating 30 years.* 21 pp. *https://rodaleinstitute.org/our-work/farming-systems-trial/farming-systems-trial-30-year-report/.*

Rodale Institute. 2011b. *Cover crops and no-till management for organic systems.* 16 pp. In: Reduced Tillage in Organic Systems Field Day Program Handbook. Cornell University Cooperative Extension, July 31, 2018. *https://rvpadmin.cce.cornell.edu/uploads/doc_699.pdf.*

Rodale Institute. 2015. *Farming Systems Trial Brochure,* 2 pp. *http://rodaleinstitute.org/assets/FST-Brochure-2015.pdf.*

Rosa, I., and J. Masiunas. 2008. *Transition Approaches and Soil Amendments Influence Weed Communities.* In Padgham, J. 2008. Midwest Organic Research Symposium, Feb. 21–23, 2008, *Research Summaries,* p. 29.

Rosolem, C.A., K. Ritz, H. Cantarella, M.V. Galdos, M.J. Hawkesford, W.R. Whalley, and S.J. Mooney. 2017. *Enhanced plant rooting and crop system management for improved N use efficiency.* Advances in Agronomy 146: 205–239.

Schahczenski, J. 2017. *Is organic farming risky? Overcoming crop insurance barriers to expanding organic food production and markets.* Proposal and 2017 annual report for OREI project 2014–05354. CRIS Abstracts.*

Schahczenski, J. 2018a. *Crop Insurance Options for Specialty, Diversified, and Organic Farmers.* ATTRA Sustainable Agriculture, 20 pp. *https://attra.ncat.org/attra-pub/summaries/summary.php?pub=413.*

Schahczenski, J. 2018b. *Primer on Whole Farm Revenue Protection Crop Insurance: Updates for 2018.* ATTRA Sustainable Agriculture, 4 pp. *https://attra.ncat.org/attra-pub/download.php?id=595.*

Schonbeck, M., D. Jerkins, and J. Ory. 2016. *Taking Stock: Analyzing and Reporting Organic Research Investments, 2002–2014.* Organic Farming Research Foundation (*www.ofrf.org*), 222 pp.

Schonbeck, M., D. Jerkins, and J. Ory. 2017. *Soil Health and Organic Farming: Building Organic Matter for Healthy Soils: An Overview.* Organic Farming Research Foundation (*www.ofrf.org*), 39 pp.

Simon, Pl, M. Colley, L. MeKenzie, J. Zystro, C. McCluskey, L. Hoagland, P. Roberts, J. Colquhoun, L. du Toit, J. Nunez, E. Silva, and T. Waters. 2016a. *The CIOA (Carrot Improvement for Organic Agriculture) Project: New Sources of Nematode Resistance and Evidence that Location, Cropping System, and Genetic Background Influence Carrot Performance.* Pp. 26–31 in Proceedings of the 8th Organic Seed Growers Conference February 4–6, 2016, Corvallis, OR. *http://seedalliance.org/publications#publication_category_title_13.*

Simon, P.W., J. Navazio, M. Colley, L. Hoagland, and P. Roberts. 2016b. *Carrot improvement for organic agriculture with added grower and consumer value.* Final report on OREI project 2011–01962. CRIS Abstracts.*

Six, J., S.D. Frey, R.K. Thiet, and K.M. Batten. 2006. *Bacterial and Fungal Contributions to Carbon Sequestration in Agroecosystems.* Soil Sci. Soc. Am. J. 70(2): 555–569.

Sullivan, D.M., and N.D. Andrews. 2012. *Estimating plant-available nitrogen release from cover crops.* Pacific Northwest Extension publication PNW 636. 23 pp. *http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/34720/pnw636.pdf.*

Sullivan, D.M., E. Peachey, A.L. Heinrich, and L.J. Brewer. 2017. *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon.* Oregon State Extension Bulletin EM 9165.

Sun H., P. Koal, D. Liu, G. Gerl, R. Schroll, A. Gattinger, R.G. Joergensen, and J.C. Munch. 2016. *Soil microbial community and microbial residues respond positively to minimum tillage under organic farming in Southern Germany.* APPL. SOIL ECOL. 108: 16–24.

Thakur, A.K., N.T. Uphoff, and W.A. Stoop. 2016. *Scientific Underpinnings of the System of Rice Intensification (SRI): What Is Known So Far?* ADVANCES IN AGRONOMY 135: 147–179.

Thompson, L., C. Burr, K. Glewen, G. Lesoing, J. Rees, and G. Zoubek. 2016. *Impact of Cover Crops on Corn and Soybean Yield in Nebraska On-Farm Research.* Midwest Cover Crop Council. *http://mccc.msu.edu/wp-content/uploads/2016/12/NE_2016_Impact-of-Cover-Crops-on-Corn-and-Soybean-Yield-in-Nebraska-On-Farm-Research.pdf.*

Toonsiri, P., S.J. Del Grosso, A. Sukor, and J.G. Davis. 2016. *Greenhouse Gas Emissions from Solid and Liquid Organic Fertilizers Applied to Lettuce.* J. ENVIRONMENTAL QUALITY Vol. 45 No. 6, p. 1812–1821.

Turner, S. 2015. *Evaluation of carrot (**Daucus carota, L.**) for traits related to early seedling establishment and canopy growth at different planting densities in organic systems.* 2015 Organic Agriculture Research Symposium, recording at *http://eorganic.info/node/12972.*

USDA, Agriculture Research Service (ARS), 2018. *Cover Crop Chart,* V 3.0. Northern Great Plains Research Laboratory at Mandan, ND. 74 pp. 1. *https://www.ars.usda.gov/plains-area/mandan-nd/ngprl/docs/cover-crop-chart/.*

USDA National Organic Program (NOP) Final Rule. *https://www.ams.usda.gov/rules-regulations/organic.*

USDA Natural Resources Conservation Service (NRCS). *Conservation Practice Standards. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849.*

USDA NRCS. 2013. *NRCS Cover Crop Termination Guidelines Non-Irrigated Cropland. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167871.pdf.*

USDA Risk Management Agency (RMA) and Federal Crop Insurance Corporation (FCIC). 2016. *Good Farming Practice Determination Standards Handbook, FCIC-Approved Standards and Procedures for Administering Good Farming Practice Decisions and Determinations for the 2017 and Succeeding Crop Years.* FCIC 14060 (12/2016), 69 pp.

USDA Sustainable Agriculture Research and Education (SARE), 2014, 2014, 2015, 2016, and 2017. *Annual cover crop survey reports. http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/Cover-Crop-Surveys.*

Van Geel, M., E. Verbruggen, M. De Beenhouwer, G. van Rennes, B. Lievens, and O. Honnay. 2017. *High soil phosphorus levels overrule the potential benefits of organic farming on arbuscular mycorrhizal diversity in northern vineyards.* AGRICULTURE, ECOSYSTEMS, AND ENVIRONMENT 248: 144–15.

Wander, M.M. 2015a. *Nutrient budget basics for organic farming systems.* 6 pp. *http://articles.extension.org/pages/18794/nutrient-budget-basics-for-organic-farming-systems.*

Wander, M.M., 2015b. *Soil Fertility in Organic Farming Systems: Much More than Plant Nutrition. http://articles.extension.org/pages/18636/soil-fertility-in-organic-farming-systems:-much-more-than-plant-nutrition.*

Wander, M., N. Andrews, and J. McQueen. 2016. *Organic Soil Fertility. http://articles.extension.org/pages/18565/organic-soil-fertility.*

Wander, M.M., S.J. Traina, B.R. Stinner, and S.E. Peters. 1994. *Organic and Conventional Management Effects on Biologically Active Soil Organic Matter Pools.* SOIL SCI. SOC. AM. J. 58: 1130–1139.

Wander, M.M., C. Ugarte, E. Zaborski, and E. Phillips. 2014. *Organic systems and climate change.* Proposal and final report for ORG project 2010–03954. CRIS Abstracts.*

Williams, A., A.S. Davis, A. Jilling, A.S. Grandy, R.T. Koide, D.A. Mortensen, R.G. Smith, S.S. Snapp, K.A. Spokas, A.C. Yannarell, and N.R. Jordan. 2017. *Reconciling opposing soil processes in row-crop agroecosystems via soil functional zone management.* AG. ECO. ENV. 236: 99–107.

Worthington, M., S.C. Reberg-Horton, G. Brown-Guedira, D. Jordan, R. Weisz, and J. P. Murphy. 2015. *Morphological Traits Associated with Superior Weed Suppressive Ability of Winter Wheat against Italian Ryegrass.* CROP SCIENCE 55: 50–56.

Wortman, S., C. Francis, R. Drijber, and J. Lindquist. 2016. Cover Crop Mixtures: Effects of Diversity and Termination Method on Weeds, Soil, and Crop Yield. Midwest Cover Crop Council, *http://mccc.msu.edu/wp-content/uploads/2016/12/NE_2016_Cover-Crop-Mixtures_-Effects-of-Diversity-and-Termination.pdf.*

Zuber S.M., and M.B. Villamil. 2016. *Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities.* SOIL BIOL. BIOCHEM. 97: 176–187.

* For project proposal summaries, progress and final reports for USDA funded Organic Research and Extension Initiative (OREI) and Organic Transitions (ORG) projects, enter proposal number under "Grant No" and click "Search" on the CRIS Assisted Search Page at:

http://cris.nifa.usda.gov/cgi-bin/starfinder/0?path=crisassist.txt&id=anon&pass=&OK=OK.

Note that many of the final reports on the CRIS database include lists of publications in refereed journals that provide research findings in greater detail.

Notes *

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REPORT 3

Soil Health and Organic Farming Organic Practices for Climate Mitigation, Adaptation, and Carbon Sequestration

An Analysis of USDA Organic Research and Extension Initiative (OREI) and Organic Transitions (ORG) Funded Research from 2002–2016

By Mark Schonbeck, Diana Jerkins, Lauren Snyder

Thank you to National Co+op Grocers for supporting this project.

* **Editor's note:** the report as submitted contains two blank pages for taking of notes. For publishing purposes they are not reproduced here.

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Introduction

Climate change threatens agriculture and food security across the U.S. and around the world. Rising global mean temperatures have already intensified droughts, heat waves, and storms, and altered life cycles and geographical ranges of pests, weeds, and pathogens, making crop and livestock production more difficult. Intense rainstorms aggravate soil erosion and complicate water management, and higher temperatures accelerate oxidation of soil organic matter. Warming climates modify crop development regulated by growing degree-days or "chill hours," and threaten production of perennial fruit and nut crops that have strict chilling requirements to initiate growth and fruit set. Thus, agricultural producers have a major stake in efforts to curb further climate change, as well as improving the resilience of their farming and ranching systems to the impacts of climate disruption.

Today's climate changes are driven largely by three greenhouse gases (GHG): carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Prior to the industrial era, the world's vegetation, soil life, and fauna mediated a vitally important balance between emissions and uptake of atmospheric CO_2, CH_4, and N_2O. Modern industrial civilization has upset this balance, resulting in a sharp rise in atmospheric concentrations of all three GHG since 1850, leading to the onset of global climate change in the late 20th century. Agricultural activities affect climate through direct GHG emissions and impacts on the soil and plant biomass components of the global carbon (C) cycle (Cogger, *et al.,* 2014; Harden, *et al.,* 2018).

The USDA Natural Resources Conservation Service (NRCS) defines soil health as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans." Healthy soils host a diversity of beneficial organisms, grow vigorous crops, enhance agricultural resilience (crop and livestock ability to tolerate and recover from drought, temperature extremes, pests, and other stresses), and help regulate the global climate by converting organic residues into stable soil organic matter (SOM) and retaining nutrients, especially nitrogen (N) (ITPS, 2015; Moebius-Clune, *et al.,* 2016). **Thus, building soil health through sustainable or-**

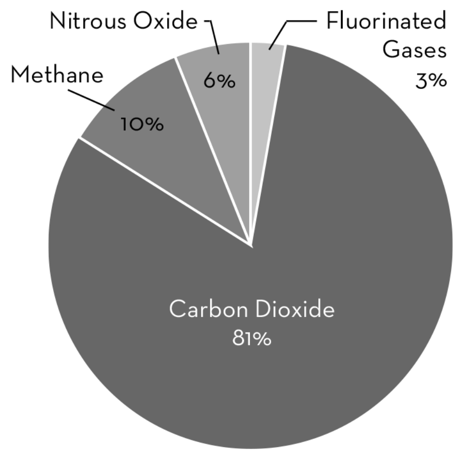
ganic management practices can mitigate GHG emissions and lessen the impacts of climate change on production.

Direct Greenhouse Gas Emissions in Agriculture

In addition to fossil-fuel-related CO_2 emissions from field operations and embodied in fertilizers and other inputs, agricultural operations emit N_2O and CH_4, whose 100 year global warming potentials (GWP) are about 310 and 21 times that of CO_2, respectively (IPCC, 2015).*

> *Although CO_2 accounts for the largest percentage of GHG emissions, N_2O and CH_4 are much more potent greenhouse gases. Methane has roughly 20 times the global warming potential (GWP) of CO_2, and N_2O has about 310 times the GWP of CO_2. The GWP of a given gas is a function of how long it remains in the atmosphere and its ability to absorb energy. Therefore, while cutting carbon emissions is an important part of combating climate change, we also need to develop organic practices that reduce N_2O and CH_4 emissions.*

U.S. Greenhouse Gas Emissions in 2016



EPA 2016.

Most agricultural N_2O is emitted during de-nitrification and other microbial transformations of soluble N in cropland and grassland soils that have been fertilized with synthetic N and/or manure (Burger, *et al.,* 2005; Charles, *et al.,* 2017; Cogger, *et al.,* 2014). Major sources of CH_4 emissions include "enteric CH_4" released by ruminant livestock, and anaerobic microbial metabolism in flooded paddy rice soils (IPCC, 2014). Manure storage facilities (especially liquid manure systems such as lagoons) and inadequately aerated composting operations can emit both CH_4 and N_2O (Richard and Camargo, 2011).

The International Panel on Climate Change (IPCC) estimated that direct agricultural GHG emissions accounted for 12% of total global anthropogenic (human caused) GHG emissions (IPCC, 2014). These emissions were attributed to livestock enteric CH_4 (~35% of agricultural CO_2-Ceq), N_2O from fertilized or manured soils (~35% of agricultural CO_2-Ceq), CH_4 from rice cultivation (~10%) and manure storage (~8%), and CO_2 from biomass burning, cultivation of peat soils, and other sources (12%) (Tubiello, *et al.,* 2013; IPCC, 2014).

In the U.S., the Environmental Protection Agency estimated that, in 2016, direct agricultural GHG emissions account for 8.6% of the nation's total anthropogenic GHG (EPA, 2018). Soil N_2O emissions accounted for 50.4% of agricultural GHG (reflecting heavier use of N fertilizers in the U.S., livestock enteric CH_4 for 30.2%, manure management facilities 15.2%, rice cultivation 2.4% (relatively low rice acreage in U.S.), and CO_2 from field burning and from lime and urea applications 1.7%. Total direct agricultural GHG emissions have increased 17% since 1990, driven

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*Throughout this Guide, figures for GHG emissions and their impacts are discussed in terms of their carbon dioxide carbon equivalents (CO_2-Ceq), based on IPCC estimates of 100 year GWP, Thus, 1 lb N emitted as N_2O = 133 lb C emitted as CO_2 (or CO_2-Ceq), and 1 lb C emitted as CH_4 = 7.6 lb CO_2-Ceq.

largely by increased use of liquid manure management systems, resulting in a 68% increase in manure facility GHG emissions (EPA, 2018).

The global IPCC report and U.S.-focused EPA analysis do not include CO_2 emissions from farm machinery and embodied energy in fertilizers and other inputs; these were subsumed under the categories of energy for transportation, machinery, and industrial processes. In a Washington State University analysis that categorized these CO_2 emissions as agricultural, N_2O (from all sources) accounted for 57% of direct U.S. agricultural GHG, CH_4 for 26%, and CO_2 for just 17% (Carpenter-Boggs, *et al.,* 2016). In conventional agriculture, N fertilizer accounts for a substantial part of the CO_2 emissions, since industrial N fixation releases about 4 lb CO_2 per lb fertilizer N (Khan, *et al.,* 2007).

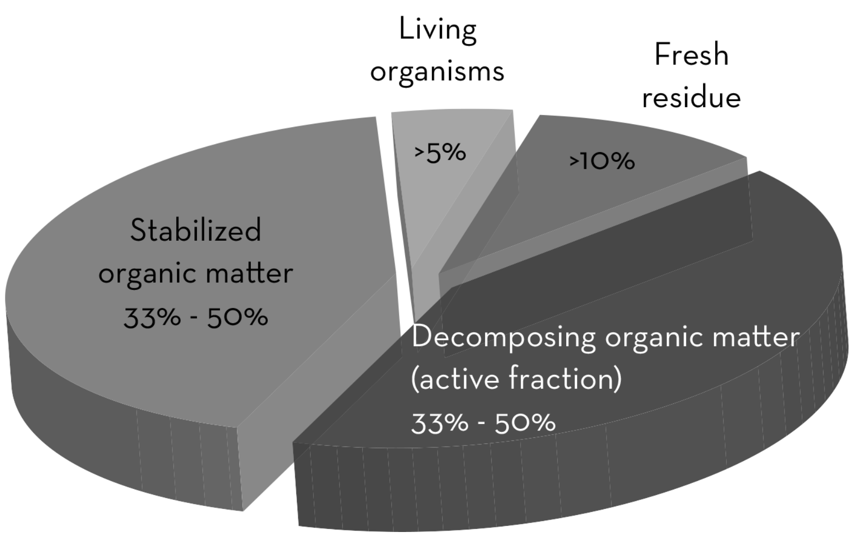
Soil, Agriculture, and the Global Carbon Cycle

Plant photosynthesis, the foundation of all life on Earth, converts atmospheric CO_2 into organic (carbon-based) compounds, which are retained in plant biomass and delivered to the soil in plant residues and root exudates. As the soil life digests plant residues, about 15–35% of the annual plant carbon input remains in the soil beyond the current season as soil organic carbon (SOC), the "backbone" (58% by weight) of soil organic matter (SOM) (Brady and Weil, 2008). Thus, in all natural and agricultural ecosystems, *the living plant is the primary source of SOC, and the soil life mediates soil C sequestration.*

The SOC is comprised of several components, including *microbial biomass carbon* (MBC), *active or labile SOC* (readily decomposed by soil life, with a residence time in the soil of a few weeks to a few years) and *stable SOC* (resistant to or protected from decomposition, residence time of decades to millennia). Soil micro- and macro-organisms (collectively known as the *soil food web* or *soil biota*) play a central role in two vital processes in the soil C cycle: *mineralization*, in which active SOC is decomposed to release CO_2 and plant nutrients, and *stabilization,* in which active SOC is converted to stable forms that are protected within soil aggregates, adhered to clay and silt particles, or chemically resistant to decomposition. Both processes help regulate climate, as mineralization is vital for ongoing plant nutrition and growth (formation of new organic C), while stabilization directly sequesters SOC.

> ***Mineralization** is the process by which soil organisms consume active SOC as their "food," thereby decomposing it into CO_2 and plant nutrients.*
> ***Stabilization,** also mediated by soil life, converts active SOC to more stable forms that are physically protected within soil aggregates, strongly adhered to soil minerals, or chemically resistant to decomposition.*

Figure 1. Components of soil organic matter (SOM)



> *Soil life processes fresh organic residues into SOM, converting 10–40% of the carbon in the residues into SOC. While active SOC turns over relatively rapidly, more stable fractions can remain sequestered for decades to mil-*

lennia. More than ½ of the world's SOC occurs below the plow layer, where it is less subject to decomposition. Most of this deep SOC is derived from plant roots; thus, including crops with deep, extensive root systems in the rotation play an important role in SOC sequestration.

Agriculture exerts multiple impacts on the global C cycle. Harvest removes a significant portion of crop-fixed C, leaving less for the soil. Tillage and overgrazing accelerate decomposition of SOM, and expose the soil to wind and water erosion, which remove SOM-rich soil particles and cause major SOC losses (Lal, 2003; Olson, *et al.,* 2016; Osmond, *et al.,* 2014; Teague, *et al.,* 2016).

Clearing land for agriculture is especially destructive to SOC and plant biomass C. Historically, deforestation and other land use changes accounted for 30% of total anthropogenic GHG emissions between 1750 and 2011. These losses have slowed in recent decades and now represent 8–12% of total emissions (IPCC, 2014; Tubiello, *et al.,* 2013). Converting temperate forest or prairie to cropland can degrade 30–50% of native SOC over a 50 year period, and clearing tropical forest can destroy 75% within 25 years (Brady and Weil, 2008; Lal, 2016; Olson, *et al.,* 2016, 2017). Since the dawn of agriculture 10,000 years ago, land use conversion has oxidized some 516 billion tons ** of biosphere C (SOC, vegetation, wetlands) to CO_2 (Lal, 2016), equivalent to 34 years' worth of total global GHG at current emissions rates.

The soil plays a central role in the global C cycle, and the capacity to absorb and hold C is a vital function of healthy soil. Total SOC held in the world's soils (~1,650 billion tons) is nearly 30% greater than the sum of C in all living organisms plus atmospheric CO_2 (Carpenter-Boggs, *et al.,* 2016; Lal, 2015). The SOC turns over (is degraded to CO_2) at about 66 billion tons annually (Brady and Weil, 2008). Most of the SOC is replenished through photosynthesis, but net losses have been estimated at about 2 billion tons C per year, ½ of which results from soil erosion (Brady and Weil, 2008; Harden, *et al.,* 2018; Lal, 2003). When these SOC losses are added to direct agricultural GHG emissions, agriculture and land use account for about 25% of global anthropogenic GHG (IPCC, 2014; Teague, 2018).

Improved farming and land management practices can reverse this trend, resulting in carbon sequestration, a net conversion of CO_2-C into SOC. For example, organic cropping systems often accrue more SOC than conventional systems in long-term trials (Delate, *et al.,* 2015b; Cavigelli, *et al.,* 2013; Rodale Institute, 2015). While individual practices such as cover cropping and no-till can sequester some C, integrated systems such as conservation agriculture, regenerative cropping, agroforestry, and adaptive multipaddock grazing (AMP) show much greater C sequestration potential (*Table 1*). Planting depleted or marginal cropland to perennial sod or trees also stores substantial C in soil and plant biomass (Feliciano, *et al.,* 2018; Jones, 2010). Cropland soils adjacent to tree lines (boundary plantings or alley crops) benefit from leaf litter, which enhances SOC and fertility up to a distance equal to tree height (Pardon, *et al.,* 2017).

The potential to design farming practices for C sequestration has drawn public attention to organic and sustainable agriculture as part of the solution to the global climate crisis (Ohlson, 2014). In 2015, the USDA announced ten *Building Blocks for Climate Smart Agriculture and Forestry.* The NRCS Conservation Stewardship Program includes GHG mitigation as a component of the air quality resource concern (USDA, 2016; USDA NRCS). In December 2015, the Paris Climate Summit (Conference of Parties) launched the "4 per Thousand Initiative" to absorb 25% of total annual global GHG emissions by increasing global SOC stocks in the top 16″ of the soil profile by an average of 0.4% per year (Lal, 2015). This would approximately offset the world's annual agricultural GHG emissions.

USDA Building Blocks for Climate Smart Agriculture and Forestry

Building Block	NRCS Lead/Member	GHG Reduction by 2025 ($MMTCO_2e$) [1]
Soil Health	Bianca Moebius-Clune	4–18
Nitrogen Stewardship	Norm Widman, Chris Gross, Dana Ashford-Kornburger	7
Livestock Partnerships	Glenn Carpenter	21.2
Conservation of Sensitive Lands	Mike Wilson	.8

** Throughout this Guide, the English system of units is used; literature reports in metric are converted to English system. One ton (2,000 lb) = 0.908 metric ton (Mg) = 908 kilograms. One acre (43,560 sq ft) = 0.405 hectare.

USDA Building Blocks for Climate Smart Agriculture and Forestry—Continued

Building Block	NRCS Lead/Member	GHG Reduction by 2025 ($MMTCO_2e$)[1]
Grazing and Pasture Lands	Joel Brown, Sid Brantly, Dana Larsen	1.6
Private Forest Growth and Retention	Eunice Padley, Dan Lawson	4.8
Stewardship of Federal Forests	——	2.5
Promotion of Wood Products	——	19.5
Urban Forests	——	0.1
Energy Generation and Efficiency	Rebecca MacLeod	60.2
Metrics and Quantification	Adam Chambers, Mike Wilson, Katie Cerretani	Total = 122–136

[1] $MMTCO_2e$ refers to metric tons of CO_2 equivalent.

This plan is designed to help farmers, ranchers, forestland owners, and rural communities respond to climate change. The ten "building blocks" include a range of technologies and practices to reduce greenhouse gas (GHG) emissions, increase carbon storage, and generate clean renewable energy:

Conservative estimates of potential climate mitigation through sustainable farming range from reducing U.S. agriculture's GHG footprint by a few percent (Galik, *et al.,* 2017; Powlson, *et al.,* 2011) to cutting it by ½ (Chambers, *et al.,* 2016). Reported SOC gains from conservation practices such as no-till or surface residue retention vary widely and often occur near the surface where the accrued SOC is vulnerable to future mineralization (Powlson, *et al.,* 2016). Based on these considerations, Powlson, *et al.,* (2011, 2016) recommend that mitigation efforts focus on soil and nutrient management to minimize emissions of the more powerful GHG, CH_4 and N_2O.

In contrast, other analyses suggest that widespread adoption of integrated systems can make U.S. agriculture carbon-negative (Harden, *et al.,* 2018; Teague, *et al.,* 2016), and even offset all anthropogenic GHG emissions (Rodale Institute, 2014). However, when soil stewardship improves, SOC levels rise steadily for several years or decades, then level off as soil C dynamics reach a new steady state (Brady and Weil, 2008; Lugato, *et al.,* 2018). Such "SOC saturation" has been observed in long-term organic farming systems trials (Rodale Institute, 2015, Carpenter-Boggs, *et al.,* 2016), and after cropland conversion to pasture (Jones, 2010; Machmuller, *et al.,* 2015). Lal (2016) estimated that SOC levels in managed lands that currently average 55% of their native levels, could be restored to 80% through known best practices, and potentially to 100% or higher through future innovations. Overall, findings to date suggest that widespread implementation of today's best soil management practices could achieve the goal of the 4 per Thousand Initiative announced at the 2015 Paris Climate Summit (*Table 1*).

Table 1. Per-acre annual C sequestration rates required to achieve three GHG mitigation goals

Global GHG Mitigation Goal	SOC seq. lb/ac-year[1]	References
Offset direct agricultural GHG emissions	[2] 325	Richard & Camargo, 2011
Offset 25% human-caused GHG emissions thru 4 per Thousand Initiative	[2] 660	Lal, 2016
Offset all human-caused GHG emissions	[2] 2,470	Teague, *et al.,* 2016

[1] Carbon sequestered as SOC.
[2] Based on C sequestration on the world's ~12.2 billion acres of agricultural lands, including 3.51 billion acres cropland and 8.65 billion acres grazing lands.

Table 2. SOC accrual rates estimated for various farming systems and practices

	SOC seq. lb/ac-year	References
Practice: cropland:		

Table 2. SOC accrual rates estimated for various farming systems and practices—Continued

	SOC seq. lb/ac-year	References
Organic system (*vs.* conventional), long-term field crop farming systems trials	[1] 400–600	Coulter, 2012; Delate, *et al.,* 2015b; Cavigelli, *et al.,* 2013; Rodale, 2015
Continuous no-till	510	West and Post, 2002
Diversified crop rotation (*e.g.,* 4 year 4 crops *versus* 2 year corn-soy)	180–470	West & Post, 2002; Alhameid, *et al.,* 2017; Lehman, *et al.,* 2017
Cover crop (NRCS practice) [2]	135–195	Chambers, *et al.,* 2016
Cover crop with no-till	440–800	Lal, 2015
Conservation Agriculture [3]	600–1,000	Lal, 2016
Regenerative cropping system [4]	2,400	Aguillera, *et al.,* 2013, Gattinger, *et al.,* 2012, Teague, *et al.,* 2016
Practice: grazing lands:		
Prescribed grazing (NRCS practice) [2]	150–400	Chambers, *et al.,* 2016
Adaptive multipaddock grazing (AMP)	2,400	Machmuller, *et al.,* 2015; Wang, *et al.,* 2015; Teague, *et al.,* 2016
Practice: Perennial conservation plantings:		
Field border, filter strip, other herbaceous perennial conservation planting (NRCS) [2]	375–850	Chambers, *et al.,* 2016
Converting cropland to grassland/prairie	≥2,000	Jones, 2010
Conservation Reserve Program (NRCS)	[5] 3,600	Manale, *et al.,* 2016
Agroforestry, tropical region [6]	[5] 6,320	Feliciano, *et al.,* 2018
Agroforestry, temperate region [6]	[5] 3,700	Feliciano, *et al.,* 2018
Agroforestry, arid to semiarid regions [6]	[5] 2,400	Feliciano, *et al.,* 2018

[1] Based on differences in total SOC between organic and conventional farming systems.
[2] For NRCS Conservation Practice Standards, visit: *https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849*.
[3] Conservation agriculture integrates diversified crop rotation, high biomass cover crops, no-till, organic soil amendments, and limited use of synthetic inputs.
[4] Regenerative cropping is similar to conservation agriculture, and includes "biotic fertilizer" to feed the soil biota, strong emphasis on legumes and other organic N sources, and crop-livestock integration.
[5] Soil + aboveground biomass C sequestration.
[6] Based on a review of various agroforestry practices such as silvopasture, alley cropping, permaculture home gardens, and transitioning cropland or degraded land to woodlot or forest.

Organic Agriculture, Soil, and Climate

The USDA National Organic Program (NOP) Standards mandate best conservation management practices, including diversified crop rotation, cover cropping, careful nutrient management, and other practices to build SOC and protect soil health (USDA National Organic Program Final Rule). The main difference between organic and conventional approaches to soil conservation, SOC, and climate mitigation is that organic farming excludes the *chemical* disturbance of synthetic fertilizers and pesticides, but allows judicious tillage; while non-organic conservation agriculture seeks to eliminate the *physical* disturbance of tillage, but allows judicious use of synthetic fertilizers, herbicides, and other crop protection chemicals when necessary. Extensive research indicates that the organic approach has potential to sequester C and mitigate GHG emissions, but that further research and development is needed to fully realize this potential (see *Concept #1* on page 10).

In addition to sequestering C and mitigating GHG emissions, building soil health can contribute to the resilience of the production system to abiotic stresses, including those related to climate change (Blanco-Canqui and Francis, 2016; Lal, 2016). Organic systems tend to give somewhat lower yields than conventional (Ponisio, *et al.,* 2014), yet yield *stability* (resilience) may be improved. For example, the organic system in a Rodale long-term trial has sustained corn yields in drought years when conventional corn yields were reduced (Rodale Institute, 2014). In another instance, regenerative range management helped a Texas ranch maintain its herd through the extreme drought of 2012 that forced other ranchers to sell livestock (Lengnick, 2016).

***Concept #1** Estimating the Climate Mitigation Potential of Organic Farming*

Organic farming practices can enhance the soil's capacity to sequester carbon. However, assessments of the overall climate impacts of organic farming range from substantial net GHG mitigation (Rodale Institute, 2014; Scialabba, 2013), to a net increase in agricultural GHG emissions as the organic industry has grown in the U.S. (McGee, 2015). There are concerns that lower crop yields in organic production reduce crop residue returns to the soil and increase GHG emissions *per unit output*

(Lorenz & Lal 2016); greater reliance on tillage to manage weeds and cover crops degrades SOM (USDA, NRCS, 2011), and SOC gains from off-farm organic inputs do not represent net C sequestration (Gattinger, *et al.,* 2012).

One valuable tool for resolving this question is to conduct a *meta-analysis,* a quantitative review of multiple studies across diverse regions, climates, and soils. Highlights from recent meta-analyses, reviews, and large-scale studies include:

- Soil samples from 659 organic fields and 728 conventional fields across the U.S. showed 13% higher total SOM and 53% higher stable SOM ("humic substances") in organically managed soils compared to conventional (Ghabbour, *et al.,* 2017).
- In 56 studies in humid-temperate, arid, and tropical regions on six continents, organic systems averaged 19% higher total SOC, 41% higher microbial biomass C, and 32–84% higher levels of several enzymes important to nutrient cycling (Lori, *et al.,* 2017).
- In 20 studies across five continents, organic systems accrued an average of 490 lb C/ac-yr compared to just 80 lb C/ac-yr for conventional systems (Gattinger, *et al.,* 2012).
- In six long-term farming systems trials in CA, IA, MD, MN, PA, and WI, organic systems accrued more SOC than conventional (Delate, *et al.,* 2015b). Organic systems with tillage outperformed conventional no-till in the MD trial (Cavigelli, *et al.,* 2013).
- In a meta-analysis of 38 studies, organic N sources lost about 0.57% of their N content as N_2O, compared to 1.0% or more for synthetic N fertilizers (Charles, *et al.,* 2017).
- Based on 12 studies, organically managed soils emitted significantly less N_2O and absorbed slightly more CH_4 per acre than conventional soils; however soil GHG emissions per unit output were slightly higher for organic systems (Skinner, *et al.,* 2014).
- Organic systems showed lower total GHG emissions per unit output than conventional in 72 out of 121 direct comparisons, while the remaining 49 comparisons showed similar or greater GHG emissions in the organic systems (Lee, *et al.,* 2015).
- A review of 115 studies with over 1,000 observations found organic yields averaging 19% lower than conventional yields (Ponisio, *et al.,* 2014). See *Concept #2* on page 22 for more.
- Statistical analysis of U.S. agriculture indicates that the growth in USDA certified organic acreage has correlated with an increase in agricultural GHG emissions, likely because many organic farms have not adopted integrated, sustainable, SOC-building systems (McGee, 2015). See *Concept #3* on page 27 for more.

Bottom Line

Best organic management practices can build SOC and soil health, and potentially reduce GHG emissions. However, further research, development, demonstration, and adoption of *sustainable* organic systems is needed to optimize net climate impact.

Challenges in Carbon Sequestration and Greenhouse Gas Mitigation in Organic Farming Systems

Throughout the history of organic agriculture, practitioners have emphasized environmental stewardship. In a recent national survey, more than 86% of 615 participants in the NRCS Environmental Quality Incentives Program (EQIP) Organic Initiative cited "concerns about environment" as a reason for adopting organic practices, compared to just 61% motivated by business opportunities offered by organic markets (Stephensen, *et al.,* 2017).

Carbon Sequestration

Organic producers face several challenges in assessing and optimizing the impacts of their practices on SOC and the farm's net carbon balance.

1. Total SOC, which usually accounts for about 58% of SOM, changes slowly in response to management and climate factors, making it difficult to assess short-term (<10 years) trends in soil C sequestration. Several indices of biologically active SOC respond more rapidly to management, but they are not yet widely available through standard soil test labs. Of these, permanganate oxidizable carbon (PO_XC) reflects SOC stabilization processes, the Solvita soil respiration test (which measures potentially mineralizable carbon or PMC) reflects SOC mineralization, and both SOC stabilization and mineralization are positively correlated with crop yields (Hurisso, *et al.,* 2016). Field measure-

ment protocols have been developed for both indices (Moebius-Clune, *et al.,* 2016). However, further research is needed to develop region- and soil-specific guidelines for interpretation of results (Roper, *et al.,* 2017).

2. Soil samples to determine total SOM (*e.g.,* standard soil tests), or active SOC are normally taken from the surface to a depth of 6″ (Moebius-Clune, *et al.,* 2016). Although biological activity is greatest near the surface, 53% of the world's SOC is located from 12″ to 39″ below the surface (Lal, 2015) where SOC residence time is much longer (Lehmann and Kleber, 2015). Root-derived SOC can play a key role in long-term SOC sequestration, provided that rotations include crops with deep, extensive root systems and soil conditions favor their full development (Kell, 2011; Rosolem, *et al.,* 2017). Deep rooted cover crops such as forage radish or cereal rye can relieve hardpan and enhance rooting depth and yield of future crops (Gruver, *et al.,* 2016; Marshall, *et al.,* 2016). Gypsum applications can ameliorate root-inhibiting excesses of soluble aluminum (Al) in certain highly weathered soils (Rosolem, *et al.,* 2017). Standard soil tests can track long-term (>10 year) trends in topsoil SOC, but do not reflect the efficacy of crop rotation and soil management in building deeper SOC.
3. The long-term fate of newly-generated SOC is difficult to predict and monitor. Relationships among organic C input, soil biological activity, and long-term C sequestration are complex. Fresh organic residues undergo a dynamic process of decomposition and transformation by the soil life. Half or more of the added C is converted back to CO_2 via microbial respiration, and the balance becomes microbial biomass C and SOC (Grandy and Kallenbach, 2015), some of which turns over within a few years, while the rest remains sequestered for decades to millennia. Many factors—quality of organic inputs, management practices, species composition and activity of the soil food web, soil type and texture, soil moisture, climate, and weather extremes—influence SOC sequestration (McLauchlan, 2006). For example, much of the SOC gained during no-till accrues within aggregates near the soil surface, and is readily destabilized by a single tillage pass (Grandy, *et al.,* 2006; Kane, 2015). Generally, more plant root biomass C (35–40%) becomes stable SOC than shoot biomass C (15–20%) (Brady and Weil, 2008; Rasse, *et al.,* 2005). Diverse organic inputs with varying C:N ratios tend to build more SOC than single-source materials with low C:N (*e.g.,* poultry litter) or high C:N i (*e.g.,* corn residues) (Cogger, *et al.,* 2013; Fortuna, *et al.,* 2014; Grandy and Kallenbach, 2015).

Soil analyses for various soil carbon fractions help tell how much carbon plants have pulled from atmospheric CO_2 and stored in soil organic matter. USDA ARS

4. While plants sequester SOC as they grow and die *in situ,* SOC from compost and other amendments from off-farm sources represents imported, not sequestered, C (Powlson, *et al.,* 2011). In a review of multiple studies, Gattinger (2012) found that, although organic systems tend to have higher SOC than conventional systems, imported C may account for 40% of the SOC increase measured in organic systems. Therefore, although organic systems have higher SOC, a substantial portion does not contribute to carbon sequestration.

Yet, depending on how it is managed, compost can help stabilize SOC (Bhowmik, *et al.,* 2017; Reeve and Creech, 2015). Compost and cover crops together build stable SOC while cover crops alone yield more active SOC that is readily mineralized through microbial respiration (Hurisso, *et al.,* 2016). In several field trials, cover crops with manure or compost application have accrued more SOC than either practice alone (Delate, *et al.,* 2015a; Hooks, *et al.,* 2015). A single compost application to depleted rangeland in California boosted plant productivity and sequestered more C than was present in the compost itself (Ryals and Silver, 2013). Thus, judicious use of compost, manure, and other organic amendments may play an important complementary role with *in situ* plant growth in SOC sequestration.

The net climate impact of utilizing off-farm organic materials depends in large part on their alternative fate. Diverting food waste and yard waste from landfills or animal manure from lagoons to amend cropland, converts these materials from major GHG sources into valuable soil amendments. A life cycle analysis of applying composted manure and plant residues to grazing lands indicated a large negative GHG footprint (net mitigation), primarily through avoided CH_4 emissions, and secondarily through enhanced forage biomass and SOC on acreage receiving the compost (DeLonge, *et al.,* 2013). Carbon emissions during materials transport, and GHG emissions during the composting process, were small relative to this offset. Careful management of compost windrows to maintain aerobic conditions and avoid excessive moisture and N in the mix minimizes GHG emissions (Brown, *et al.,* 2008; DeLonge, *et al.,* 2013).

Other opportunities to avoid GHG emissions and build soil by composting organic "wastes" abound. For example, Dr. Girish Panicker (2017) states:

> *"[A]ccording to EPA, we throw away 24 million tons of dried [tree] leaves into the landfills every year . . . This is the greatest gift of nature, which contains thousands of tons of macro and micro nutrients for the succeeding plants. It is the food of our Mother Earth. It can conserve soil and water. EPA states that Americans pay $65/ton to put it in the landfill."*

Conversely, harvesting plant biomass to make compost or other organic amendments can deplete the "donor" field. Removal of crop residues (*e.g.,* corn stover) from fields can severely compromise SOC and soil health (Andrews, 2006), and intensify wind and water erosion (Blanco-Canqui, *et al.,* 2016a, 2016b). Similar concerns apply to biochar, a soil amendment created by pyrolysis of organic residues, which can help stabilize SOC, improve soil structure, and reduce N_2O emissions (Blanco-Canqui, 2017; Cai, *et al.,* 2016 Mia, *et al.,* 2017). However, the pyrolysis process releases GHG, plant biomass is consumed as pyrolysis feedstock rather than returning to the soil *in situ,* and some biochar enterprises remove forest or other native plant biomass at unsustainable rates to make the product (North, 2015).

Tips to enhance carbon sequestration:

- *Implement conservation practices, such as diversified crop rotations and reduced tillage.*
- *Consider regenerative cropping systems that integrate multiple conservation practices with judicious use of compost or other organic amendments.*
- *Incorporate agroforestry practices, such as silvopasture, alley cropping, and hedgerows.*

- *Implement management intensive rotational grazing systems.*
- *Plant marginal cropland to perennial sod or trees.*
- *Plant deep-rooted cover crops, such as forage radish or cereal rye, to enhance root biomass.*
- *Diversify crop rotations by adding deep-rooted and perennial crops.*
- *Use diverse organic inputs that vary in their C:N ratio.*
- *Combine the use of compost and cover crops.*
- *Divert food and yard waste from landfills to amend cropland.*

Finally, organic farmers can face tough choices between sequestering C and maintaining crop yields and net economic returns. Organic production relies on sufficient SOC mineralization to provide crop nutrients, which, at first glance, seems to contradict the goal of long-term SOC sequestration. Hurisso, *et al.,* (2016) state:

> *"Soil organic matter levels are the balance of C inputs to soil (through crop residues and amendments) and losses via mineralization (**i.e.,** CO_2 respiration). These dynamics (stabilization vs. mineralization) are mediated through the soil food web, which plays a large role in SOM decomposition and supports crop nutrition. Growers have a vested interest in both processes because they rely on mineralization for short-term crop productivity, but also strive for stabilization to build soil resilience, tilth, and quality."*

Compared to conventionally managed soils, organically managed soils typically have higher microbial respiration rates (PMC) and higher levels of active (PO_XC), stable, and total SOC, indicating that SOC mineralization and stabilization can be enhanced simultaneously (Hurisso, *et al.,* 2016; Lori, *et al.,* 2017).

Tillage and cultivation present a tougher challenge, as they accelerate SOC oxidation and sometimes erosion. Cover crop-intensive, organic no-till systems that maximize SOC often entail substantial yield tradeoffs, especially in the colder climates of the northern half of the U.S. (Barbercheck, *et al.,* 2008; Delate, 2013, Larsen, *et al.,* 2014). Thus, farmers often struggle to find the right balance between crop production and long-term SOC retention.

Conservation agriculture is a system that aims to achieve this balance by integrating diversified rotations, cover crops, legumes, organic soil amendments, crop-livestock integration, and continuous no-till with limited synthetic inputs to maintain high yields, build soil health, and sequester C (Delgado, *et al.,* 2011; Teague *et al.,* 2016). Best sustainable organic practices differ from conservation agriculture primarily in the complete *non*-use of synthetic inputs including herbicides, which protects soil life (Rose, *et al.,* 2016), but makes continuous no-till infeasible for annual crops. However, organic systems that reduce tillage intensity, maximize crop biomass and diversity, and use organic amendments can build more SOC than continuous conventional no-till (Cavigelli, *et al.,* 2013; Dimitri, *et al.,* 2012; Kane, 2015). Practical organic conservation tillage strategies include ridge or strip tillage, which release nutrients in crop rows and build SOC between rows (Williams *et al.,* 2017), and implements such as spaders, rotary harrows, and sweep plow undercutters, which destroy less SOC and leave soil in better condition than plow-disk or rototiller (Schonbeck, *et al.,* 2017).

Crop diversification is another practice that generally enhances SOC, especially when perennial and deep rooted crops are added to the rotation, and this SOC accrual may be more stable than that achieved through no-till (Cavigelli, *et al.,* 2013; Kane, 2015; Powlson, *et al.,* 2016; Wander, *et al.,* 1994). Increasing crop diversity also enhances soil microbial biomass, biodiversity, nutrient cycling, and other soil food web functions, (King and Hofmockel, 2017; McDaniel, *et al.,* 2014; Tiemann, *et al.,* 2015. However, adding new crops to the system can entail acquiring new production tools and skills, market research for new products, and/or reduced revenues resulting from unharvested cover or sod crops.

Nitrous oxide, methane, and total greenhouse gas "footprint" of the farming system

Nitrous oxide (N_2O) emissions from fertilized soils account for about ½ of direct GHG emissions in U.S. agriculture (EPA, 2018), and result from microbial transformations of soluble nitrogen in the form of ammonium (NH_4) and nitrate (NO_3) into N_2O. The IPCC has estimated that on average about 1% of applied fertilizer is emitted as N_2[O] (emission factor, EF). However, actual EF values for organic N sources can vary from nearly zero to as high as 7% depending on the N source and its C:N ratio, soil texture and drainage, and seasonal rainfall (Charles, *et al.,* 2017). In a meta-analysis of multiple studies, organic amendments with a high C:N ratio (*e.g.,* crop residues, paper mill sludge, *etc.*) or well-stabilized N (finished compost) had low EF (0–0.3%), while solid manures ranged from 0.3–1.0%, and liquid manure slurry and biogas digestate averaged 1.2% (Charles, *et al.,* 2017). Although a 1% loss from a 150 lb/ac N application has little economic impact on the farm, this loss in the form of N_2O negates about 200 lb C sequestration.

In conventional farming systems, N_2O emissions show direct relationships with N application rates and methods. Reliable, research-based nutrient management protocols for reducing N_2O emissions by 50% or more have been developed for field crops (Eagle, *et al.,* 2017; Millar, *et al.,* 2010). While organic N sources have a mean EF of 0.57%, and organic practices can mitigate N_2O (Cavigelli, 2010; Charles, *et al.,* 2017; Reinbott, 2015), the dynamics of N_2O emissions in organic systems are complex and challenging to manage, making it difficult to develop nutrient management protocols for organic systems. Brief, intense N_2O "spikes" can occur when high soil moisture levels and limited oxygen coincide with an abundance of readily-decomposable organic C and N; for example, when N rich organic fertilizers (*e.g.,* poultry litter) or legume green manures are tilled into moist soil (Baas, *et al.,* 2015; Bhowmik, *et al.,* 2015; Cavigelli, 2010; Han, *et al.,* 2017).

Annual cover crops usually reduce N_2O losses while they are growing (by taking up N), but may stimulate emissions after termination, especially when all-legume covers are tilled in higher-rainfall climates (Basche, *et al.,* 2014; Li, *et al.,* 2009; Rosolem, *et al.,* 2017). A recent European modeling study indicated that adding clover cover crops (terminated by tillage) to existing crop rotations would boost N_2O emissions to result in large net GHG emissions by the year 2100 (Lugato, *et al.,* 2018).

In colder climates, spring thaw/snowmelt is a high-risk time for N_2O (Thies, 2007), especially after a fall alfalfa plowdown has released an abundance of soluble N into the soil (Westphal, *et al.,* 2018). Other risk factors include soil compaction, which impedes aeration and promotes de-nitrification when soil moisture levels are high; and fine-textured (clayey) soils, in which EF values for organic N sources averaged 2.8 times those for sandy soils (Balaine, *et al.,* 2016; Charles, *et al.,* 2017).

The soil microbial community plays a central role in regulating the conversions of soil N among organic, soluble, and volatile forms, and thereby modulates N_2O emissions. Among the many benefits of arbuscular mycorrhizal fungi (AMF) are their capacity to limit N_2O emissions and build stable SOC (Hu, *et al.,* 2016, Rillig, 2004). While organic practices and reduced tillage can enhance AMF activity, heavy compost use may inhibit AMF by building up high soil P levels (Gottshall, *et al.,* 2017; Hu, *et al.,* 2016; Van Geel, *et al.,* 2017).

Agricultural methane emissions are related primarily to livestock and rice production. Livestock-related GHG emissions include enteric CH_4 and GHG released during manure storage. Pasture-based systems reduce the need for manure storage, yet 100% grass-fed cattle emit more CH_4 than animals that receive concentrates because the former diet is higher in fiber and lower in protein (Manale, *et al.,* 2016; Richard and Camargo 2011). Pastured dairy systems also create N_2O "hotspots" in areas of high stocking density where manure is concentrated, and soil becomes compacted (Luo, *et al.,* 2017).

However, life cycle analyses of management-intensive rotational grazing systems (MIG) have shown that they can sequester sufficient SOC to offset enteric and manure GHG emissions, and may reduce enteric CH_4 by ~30% through improved forage quality (Kittredge, 2016–17; Manale, *et al.,* 2016; Stanley, *et al.,* 2018; Teague, 2016–17; Wang, *et al.,* 2015)). MIG systems divide grazing lands into multiple paddocks, each grazed intensively for 0.5–3 days at high stocking rates, followed by sufficient recovery periods for the sod to regrow fully (Kittredge, 2014–15). Life cycle analyses on MIG systems in Texas, Michigan, and South Carolina showed a net negative GHG footprint (*i.e.,* mitigation), though the investigators caution that the rapid SOC accruals over the initial 5–10 years level off thereafter (Machmuller, *et al.,* 2015; Stanley, *et al.,* 2018; Wang, *et al.,* 2015).

Well-drained agricultural and grassland soils generally do not release CH_4, and may absorb small amounts of this GHG, whereas water-saturated rice paddy soils release considerable CH_4 (Richard and Camargo, 2011; Thakur, *et al.,* 2016; Topp and Pattey, 1997). Terminating cover crops in rice paddies just before flooding intensifies emissions, whereas draining rice fields for part of the season can reduce them (Dou, *et al.,* 2016; Oo, *et al.,* 2018; Tariq, *et al.,* 2017). The System of Rice Intensification (SRI), which integrates improved crop establishment techniques, compost for fertility, and non-flooded field management, can enhance soil and crop root health, improve yields, curb CH_4 emissions, and reduce total GHG emissions per ton of grain by 60% (Thakur, *et al.,* 2016).

Researchers are attempting to develop realistic models and decision tools for estimating the carbon balance and overall GHG "footprint" of a farming operation (Baas, *et al.,* 2015; Jones, 2010; Wander, *et al.,* 2014). The USDA has developed GRACEnet, a field chamber protocol for monitoring CO_2, N_2O, and CH_4 emissions in different cropping systems, thereby providing data for construction of predictive models (Parkin and Venterea, 2010). COMET Farm and COMET Planner are online tools designed to help producers in this complex task, and to identify management changes that could reduce emissions or sequester SOC. Models were initially developed for conventional production of commodity crops. Additional refinement to address minor and specialty crops and other farming systems including organic are underway. OFOOT is another tool under development by the Center for Sustaining Agriculture and Natural Resources at Washington State University, designed to help organic producers understand and improve the net GHG footprint of their farms (Carpenter-Boggs, *et al.,* 2016).

Positive feedback and the vital role of climate adaptation

Climate change itself can render C sequestration and GHG mitigation more difficult. Rising temperatures are expected to accelerate the oxidation of SOC (ITPS, 2015; Kell, 2011, Petit, 2012). Warming-related SOC losses will be especially pronounced in cold-temperate climates and in regions where permafrost thawing occurs (Harden, *et al.,* 2018; Kirschbaum, 1995). Warmer, drier winters and springs in the U.S. Corn Belt may complicate crop establishment and leave tilled soils more prone to wind erosion (Daigh and DeJong-Hughes, 2017). N_2O emissions also increase with soil temperature (Ball, *et al.,* 2007), and with mean summer temperatures (Eagle, *et al.,* 2017). Finally, rising atmospheric CO_2 levels may also stimulate N_2O formation by soil fungi (Zhong, *et al.,* 2018).

These trends highlight the urgent need to strengthen the resilience of agricultural systems to climate disruptions already underway. As noted earlier, the deeper, more biologically active soils of mature organic systems that have higher SOC can improve crop and livestock resilience to drought and other weather extremes. The soil benefits of organic practices appear especially pronounced in tropical climates (Lori, *et al.,* 2017), and thus may become more important in temperate regions as mean temperatures increase.

New risks, learning curves, and other barriers to climate-friendly organic farming

Adding new management practices to make a farming system more climate-friendly and climate resilient can initially increase financial risks as producers must acquire new knowledge and training, and often new equipment and infrastructure. The knowledge-intensive and site specific nature of organic farming is accentuated when C sequestration and climate mitigation and adaptation are added to the producer's goals. For example, a cover crop-intensive organic minimum-till system that works well in the Southeast may lead to crop failures in a colder or drier region.

Crop diversification requires careful business planning and market research to ensure sustained profitability.

For example, adding a specialty grain or legume crop to a corn-soy-wheat rotation may require new market venues for the new crop. Integrating a sod crop into the rotation builds SOC but often entails foregone income, and may be infeasible for a small-acreage market garden.

While the benefits of building soil health and sequestering SOC can lead to improved yields or yield stability in organic systems, the financial returns may not be realized for several years. In the meantime, organic producers encounter economic, infrastructural, social, and policy barriers to the adoption of climate friendly and climate resilient farming systems, including:

- Up-front costs and delayed benefits of adopting new practices.
- A steep learning curve and lack of qualified technical assistance to help producers identify and adopt the best suite of practices for their farm.
- A historical under-investment in organic agriculture research, which has contributed to the "yield gap" between organic and conventional systems (see *Concept #2* on page 22).
- A lack of crop cultivars adapted to sustainable organic production systems.
- An agriculture and food system infrastructure that perpetuates unsustainable production systems.
- Government agricultural policies and programs that create dis-incentives to crop diversification, cover cropping, and other conservation practices.
- The lack of viable carbon markets for climate-conscious producers.
- The current lack of political support for addressing climate change at a societal level.
- Social or cultural pressures that deter adoption of organic or climate friendly practices.

The bottom line is that farmers—organic or otherwise—need to make a living; thus, any management changes to sequester C or mitigate GHG emissions must also maintain or improve the farmer's net returns. If the farm goes out of business and the land undergoes commercial or residential development, its net per-acre GHG emissions may soar. For example, one study in Yolo County, California estimated that urban areas emitted *70 times* the GHG (in CO_2 equivalents) as irrigated cropland (Jackson, *et al.,* 2012). Thus, farmland preservation in itself can be seen as a climate-mitigating endeavor. In addition, our society must provide farmers with the technical, economic, infrastructure, and social support to adopt optimal soil-building, climate-friendly, and profitable systems for their farming or ranching operations.

***Concept #2** Closing the organic **versus** conventional yield gap*

One challenge that organic farmers face as they strive to improve their environmental stewardship *and* stay in business is the "yield gap." Given the lower yields often associated with organic production, the GHG footprint of organic food in carbon dioxide carbon equivalents (CO_2-Ceq) *per unit output* is not as small as might be expected based on CO_2-Ceq *per acre in production.* In addition, concerns have been raised that lower-yielding organic systems would require more acres of native vegetation to be cleared to meet humanity's food and fiber needs, which would further increase the GHG footprint of organic production.

For grain crops, the mean yield shortfall for organic production has been estimated at 19%, based on studies in 38 countries (Ponisio, *et al.,* 2014). In comparisons of organic systems with a diversified crop rotation or multicropping system *versus* a conventional monoculture or low-diversity rotation, the yield difference diminished to 8–9%. However, in comparisons in which *both* organic and conventional systems were diversified, the yield gap remained at 21%.

Much of the yield gap can be attributed to low investment in organic research and plant breeding for organic systems. Since 2002, the USDA Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) have begun to address this need (Schonbeck, *et al.,* 2016). Yet, only 1.5% of USDA research dollars currently go into organic systems, lagging behind the 5% market share for organic food. Ponisio et, *et al.,* (2014) add:

> *"Given that there is such a diversity of management practices used in both organic and conventional farming, a broad-scale comparison of organic and conventional production may not provide the most useful insights for improving management of organic systems. Instead, it might be more productive to investigate explicitly and systematically how specific management practices (**e.g.,** intercrop combinations, crop rotation sequences, composting, biological control, **etc.**) could be altered in different cropping systems to mitigate yield gaps between organic and conventional production.*
>
> *"Further, many comparisons between organic and conventional agriculture use modern crop varieties selected for their ability to produce under high-input (conventional) systems. Such varieties are known to lack important traits needed for productivity in low-input systems, potentially biasing towards finding lower yields in organic **versus** conventional comparisons. By contrast, few modern varieties have yet been developed to produce high yields under organic conditions; generating such breeds would be an important first step towards reducing yield gaps when they occur."*

Bottom Line

Today's climate and food security crises make research into sustainable organic systems more urgent than ever. The potential of plant breeding for soil health and economic viability of organic farms and ranches is discussed in the companion Guide, *Soil Health and Organic Farming: Plant Genetics, Plant Breeding and Variety Selection.*

Best Management Practices and Information Resources for Carbon Sequestration and Net Greenhouse Gas Mitigation in Organic Farming

The first steps toward creating a climate-resilient and climate-friendly farm or ranch ecosystem are to:

- Clarify your objectives and priorities.
- Inventory farm resources including soil, water, crops and livestock, infrastructure, expertise, and labor.
- Evaluate your current production practices and their potential impacts on GHG emissions and the resilience of your farming system.
- Identify opportunities to improve your operation's climate and environmental impacts while maintaining or enhancing your bottom line.
- Outline your overall strategy to achieve your objectives.

Gather the information you need on current and potential new practices or components, their C sequestration or GHG implications, and their direct costs and benefits to your operation. For example, diversifying your crop rotation can enhance SOC sequestration and reduce GHG; it also presents marketing and management challenges and an opportunity to evaluate and compare net returns of your current crops and new crops under consideration. Some valuable resources for this part of the process include enterprise budgets, business planning templates, and market information on organic farm products, available online or as Extension bulletins.

Consider seeking technical assistance from NRCS field staff or independent consultants with a commitment to agricultural sustainability and expertise in organic systems, soil health, climate in agriculture, and agricultural economics. These professionals can help you clarify goals and develop a practical and site specific strategy for your operation. NRCS has developed a nine-step comprehensive conservation planning process in which their field staff or a technical services provider works on the ground with farmers to clarify objectives, inventory resources and concerns, develop and implement a strategy, and evaluate outcomes (USDA NRCS, 2014). In addition, the Conservation Stewardship Program (*Resources, item 23*) offers high level conservation strategies that can mitigate GHG and improve resilience to weather extremes.

Factors to consider and their GHG and resilience impacts (listed in parentheses) include:

- Your soil type(s), including texture, mineralogy, profile, depth, drainage, topography, inherent strengths and constraints, and risk factors for soil erosion or degradation. NRCS Web Soil Survey (*Resources, item 22*) provides this information.
- Management history and current condition (fertility, tilth, vegetative cover) of the soil in each field or pasture.
- Tillage practices and other field operations (*CO_2 from fuel, loss of SOC, soil erosion*).
- Cover crops (*C sequestration, N uptake, reduced input needs*), termination of legume and other low C:N cover crops (*N_2O emissions*).
- Compost and other organic amendments, on- or off-farm sourcing (*soil health, SOC stabilization, nutrient cycling, soil nutrient balance, GHG impacts of manufacture and transport* ***versus*** GHG offsets for materials diverted from landfill or lagoon).
- Nitrogen applications such as poultry litter or livestock manure (*N_2O*).
- Critical times in the season or crop rotation when high levels of soil moisture and soluble N may occur together (*N_2O*).
- Flooded field production systems, *e.g.,* rice (*CH_4*).
- Livestock nutrition, forage quality, grazing and pasture/range management (*enteric CH_4 and its mitigation, N_2O "hotspots," C sequestration*).
- Manure storage facilities and composting operations (*CH_4 and N_2O*).
- Opportunities to increase plant cover (days per year), biomass, and depth and extent of living roots in the farm's cropland, pasture, or range (*enhanced C sequestration and resilience to drought, temperature extremes, and other stresses; reduced soil erosion*).
- Opportunities to diversify the crop rotation and farm enterprises (*C sequestration, resilience, including economic resilience to crop failure or market fluctuations*).
- Opportunities to plant trees, shrubs and other perennials, including orchard and other perennial crops; windbreaks, hedgerows, alley crops, silvopasture, and other agroforestry; restoration of native plant communities or wildlife habitat (*C sequestration, erosion control, resilience*).
- Opportunities to tighten nutrient cycles, such as crop-livestock integration (*N_2O mitigation, resilience*).

As you fine-tune your organic production system for soil and climate stewardship, keep in mind that adopting new crops or practices entail a learning curve and new potential risks, as well as benefits. Add one or two practices or components at a time, trying them out on a small scale first, then integrate those that support the farm's economic viability while advancing your soil health and climate mitigation/adaptation goals.

Clay soil

Sandy soil

Silty soil

Remember also that no single practice or new crop will be a "silver bullet" solution for soil health, climate, or profit. Your long-term goal is to develop an integrated systems approach, which is the essence of organic farming (see *Concept #3* on page 27).

See *Resources, items 1–5, 8, 9, 12, 14–18, 21, 22, 24* and *25* for resources to help identify and estimate GHG impacts of your farming system and practical strategies for mitigation and adaptation.

Concept #3 *Organic is More than Renouncing Synthetics and GMOs*

How full implementation of NOP Standards can sequester carbon, limit greenhouse gas emissions, and build agricultural resilience

> *"Organic agriculture is defined as having no synthetic inputs, but organic farms may or may not practice the full suite of cultivation techniques characterizing sustainable agriculture."*
>
> (Ponisio, *et al.,* 2014).

In order to become part of the climate solution, organic producers and certifiers have been urged to move beyond a narrow focus on "input substitution" (McGee, 2015) and to fully implement NOP requirements to protect natural resources, wildlife, and biodiversity (Wild Farm Alliance, 2017). The NOP Rules provides a clear roadmap to resilient, climate-friendly farming. Note, these rules are subject to change.

§*205.2 Definitions:*

"Organic Production: a production system that is managed . to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity."

§*205.202 Land Requirements:*

"[F]ield or farm parcel . . . must have distinct, defined boundaries and buffer zones . to prevent the unintended application of a prohibited substance."

- Tree and shrub plantings to meet this requirement also sequester C.

§*205.105 Allowed and Prohibited Substances:*

"[Organic] product must be produced . . . without the use of synthetic substances."

- Non-use of synthetic N stabilizes SOC, enhances microbial function, and re duces N_2O.
- Non-use of synthetic crop protection chemicals protects soil organisms that build SOC.

§*205.203 Soil fertility and crop nutrient management practice standard:*

"[T]illage and cultivation practices [must] maintain or improve physical, chemical, and biological condition of soil, and minimize erosion."

- Tilling with care and reducing tillage when practical protects SOC and soil health.

§*205.203 Soil fertility and crop nutrient management practice standard:*

"[M]anage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials . . ."

§*205.205 Crop rotation practice standard:*

"[I]mplement a crop rotation including . . . sod, cover crops, green manure crops, and catch crops that . . . maintain or improve SOM, provide for pest management, manage deficient or excess plant nutrients, and provide erosion control."

- Diversified crop rotations build microbial biodiversity and biomass, and total SOC.
- Cover crops and rotation reduce the need for applied N, and thus reduce N_2O risks.
- Cover crops, sod crops, and diversified rotations build yield stability and resilience.
- Judicious use of compost and other organic inputs stabilizes SOC and enhances soil life.

§*205.240 Pasture practice standard*[*:*]

"The producer . . . must [have] a functioning management plan for pasture. to annually provide a minimum of 30 percent of a ruminant's dry matter intake . . . "

- Management intensive grazing can build SOC, distribute nutrients, and foster resilience.

In selecting management practices, consider the following detailed lists as menus of options from which to choose. Some of the recommendations are well researched and widely applicable, while others are more specific to certain regions, soils, or production systems, and may or may not be the right choice for you. A few of the practices listed are noted as experimental; while they have shown promise, they are also potentially risky in certain circumstances.

Sequestering and conserving carbon in the soil

Extensive research has illustrated the central role of living vegetation in restoring and maintaining SOC, and has validated the four NRCS principles of soil health management as guidelines for C sequestration and resilience of the farming system. These principles are:

- Keep the soil covered year round.
- Maintain living roots throughout the soil profile as much of the year as practical.
- Minimize soil disturbance—tillage, compaction, overgrazing, chemicals.
- Energize the system with biodiversity.

The following practices and strategies can build SOC and agricultural resilience.

Grow and sequester carbon in place:

- Maintain plant cover, biomass, and living roots as much of the year as practical; avoid or minimize bare fallow periods.
  - In regions with sufficient rainfall, implement "tight" crop rotations after each harvest or cover crop termination; plant the next crop as soon as practical.
  - In semiarid conditions such as dryland grain production, grow one cash or cover crop per year to maintain SOC and soil health. If extended fallow is needed to store soil moisture, keep surface covered with plant residues.
- Diversify the crop rotation. Adding just one new crop can enhance SOC and soil health.
- Grow high biomass, multi-species cover crops in rotation with production crops.
- Include a perennial sod phase (1–3 years) in the rotation, if economically feasible.
- Close time and space gaps between crops in the rotation whenever practical. Some advanced techniques for maximizing year round living cover include:
  - Interseed or overseed cover crops into standing grain, row, or vegetable crops. Interseed cover crops into corn at the V5–V6 (~knee high) stage.
  - Roll-crimp, mow, or ridge-till cover crops before planting cash crop (*may be risky, especially in colder regions; experiment first on small area*).
  - Seed row crop into standing cover before roll-down if soil moisture is ample and good seed-soil contact can be achieved for the row crop (*may be risky; experiment first on small area*).
  - Plant intercrops of dissimilar but complementary species, for example
    - ➢ "Three sisters": corn (tall, erect, N demanding), pole beans (climbing, N fixing), and winter squash (covers ground, tolerates part shade).
    - ➢ Alternate rows of tomato (tall, need good air circulation and full sun) with beds of salad greens (low growing, appreciate light shade in summer).

- Manage for high crop root biomass and deeper root growth:
  - Include deep rooted crops (cash, cover, or sod) in the rotation.
  - Choose crop varieties with greater root mass and depth.
  - Avoid "spoon-feeding" soluble N; use slow-release fertility sources.
  - Relieve hardpan using deep-rooted cover crops (subsoil first if necessary).
  - If subsoil acidity and high Al constrains root depth, apply gypsum.
- Keep orchard and vineyard floor, and berry crop alleys covered in living vegetation. Perennial sod maintained by periodic mowing works well for established fruit crops.
- Install windbreaks, hedgerows, silvopasture, alley cropping, and other functional agroforestry plantings as appropriate to your operation.
- Convert highly erodible cropland to orchard, other perennial crops, or permanent pasture.
- Restore degraded lands, marginal cropland, and riparian or other ecologically sensitive areas to forest or prairie, with emphasis on native perennial plants and wildlife habitat.

Use organic amendments to supplement and enhance *in-situ* plant based C sequestration:

- Apply compost, manure, or other amendments. Start with on-farm or nearby sources.
- Adjust manure and compost use rates to maintain moderate soil P levels; avoid excess P.
- Combine low and high C:N cover crops and organic inputs.
- If additional organic materials from off-farm sources are needed, choose materials that would otherwise "go to waste," *e.g.,* autumn leaves or food waste headed to landfills, or manure that would otherwise be stored in a lagoon or unmanaged heap.
- Avoid inputs whose "harvest" depletes SOC on other lands (*e.g.,* corn stover biochar).
- Commercial microbial soil inoculants may be valuable when rebuilding depleted soils.
- Mycorrhizal inoculants can be valuable, especially for woody perennial crops.

Slow-release Fertility Sources:

- *Finished compost*
- *Legume-grass cover crop residues*
- *Alfalfa meal*

UC Davis.

Conserve soil carbon:

- Prevent or remedy soil erosion—it is an infamous SOC thief.
  - Reduce tillage whenever practical.

- ◦ On sloping fields, lay out raised beds or ridges approximately on contour, with gradual (0.5–1%) row grade down toward one or both edges of field. Use contour buffer strips (sod), terraces, or other soil conservation measures as warranted.
- ◦ Put steeper, highly-erodible lands in permanent cover-pasture, silvopasture, forest, orchard with sod understory, native plants, wildlife habitat, *etc.*

- Avoid breaking perennial sod, and especially native forest, prairie, wetland, or other natural ecosystems, for annual crop production.
- Avoid harvesting or "baling-off" crop residues such as corn stover or mature cover crops, especially for fuel or off-farm use. Leave residues on soil surface as long as practical.
- Carefully managed *grazing* of crop residues or cover crops as part of a crop-livestock integrated system can be compatible with soil health and SOC sequestration.
- Terminate cover crops by mowing, roll-crimping, tarping (occultation), winterkill, undercutting, or shallow tillage that leaves most of the root mass undisturbed in the soil profile (*note that no-till cover crop management can be challenging in organic systems*).
- Use ridge tillage or strip tillage to promote nutrient release in crop rows while leaving between-row soil undisturbed to maximize SOC accrual (*experimental for organic systems, has shown promise in research trials*).
- Avoid overapplying plant-available N, which can "burn up" SOC. On fertile soils, simply replenish N removed by harvest, ≤50 lb/ac for most vegetables (Wander, 2015).

For more on building SOC and soil health, see *Resources, items 2, 5, 6, 7, 9–13, 19–21, 23–25,* and the other guides in the *Soil Health and Organic Farming* series.

Minimizing nitrous oxide (N_2O) and methane (CH_4) emissions from cropland soils

Although abundant soil moisture and organic C and N during spring thaw or after green manuring have been identified as risk factors for N_2O emissions, more research is needed to better understand and minimize pulses of N_2O emissions from fertile, biologically active soils. However, the following strategies can reduce annual total N_2O emissions in organic crop production:

Know your soil properties and plan moisture management accordingly:

- Identify soil type, texture, and drainage properties to better understand N_2O risks:
  - ◦ Heavy (clay, clay loam, silt loam) soils have two to three times the N_2O "emissions factors" for organic N inputs as light (sandy loam) soils.
  - ◦ Floodplains, depressions, soils with naturally occurring hardpan ("fragipan" or "duripan"), and areas with naturally slow drainage ("moderately well drained" to "poorly drained") are likely N_2O hotspots in the farm landscape.
  - ◦ Sodic (high-sodium) soils, which occur in low-rainfall regions such as interior parts of the western U.S., often have poor, compacted structure and drain slowly.

- Remedy moderate drainage/aeration issues with deep rooted cover crops, inputs to build SOC and tilth, graded raised beds (sloping at 0.5–1% grade to field edge), or tile drains.
- Plant wetter, high-risk areas in unfertilized perennial vegetation such as grass sod, edible perennial landscape, or native woodland or wetland plant communities.
- Prevent and remedy soil compaction with deep rooted cover crops, diversified rotation, controlled traffic, and soil health building practices. For severe compaction, subsoil or chisel plow just before planting deep rooted crops.
- On irrigated crops:
    - Manage water applications to avoid prolonged periods of excessive soil moisture.
    - Monitor fields for ponding in low spots or tailwater collection areas—these can be major N_2O hotspots especially in high SOC soils.
    - In sodic soils, gypsum applications can relieve compaction, improve water relations, and prevent waterlogging during irrigation.

Manage soil nitrogen to minimize nitrous oxide emissions:

- Aim to meet most of crop N needs through the action of the soil food web on SOM and slow-release N sources, such as legume-grass cover crop residues.
- If "quick" N is needed, use concentrated N sources such as poultry litter, blood meal, manure slurry, and Chilean nitrate in moderation, perhaps 50 lb N/ac.
- Ration applied N to meet, but not exceed crop N needs.
    - Conduct simple N rate trials to assess crop response.
    - On biologically active soils, crop N need may be well below amounts recommended on a standard soil test.
    - Measure in-season soil or crop tissue nitrate-N (*e.g.,* pre-sidedress nitrate test for corn at 12″ height), to determine if more N is needed.
- Match timing of plant-available N with crop N demand, which usually peaks during the period of most rapid growth, such as the V9–V10 stage for corn.
    - Split applications of more concentrated N, such as feather or blood meal, or
    - Use in-row drip irrigation to deliver a little N each week to the crop.
- Monitor and "mop up" excess soluble N.
    - Measure soil nitrate-N after harvest. Send soil samples to a laboratory or use an in-field test kit.
    - If surplus soluble N (≥30 ppm nitrate-N) is found or expected to remain after harvest, plant a high biomass, N-demanding cover crop immediately. Intercrop or overseed before harvest, if practical.
- Avoid adding manure or other concentrated N sources or turning under succulent, high-N cover crops (green manure) when soil is wet or heavy rainfall is likely.
- For the perennial sod phase of a rotation, plant a mix of legumes with grasses and other non-legumes to minimize risk of N_2O emissions after plowdown.
- Manage for mycorrhizal fungi and other soil organisms that promote tight N cycling:
    - Avoid excess soil P and soluble N levels.
    - Monitor P levels in compost and manure, adjust application rates accordingly.
- Use mycorrhizal fungal inoculum to help restore depleted soils with low P.

Mitigate GHG risks in organic rice production and composting:

- Use the non-flooded System of Rice Intensification (SRI).
- If your rice production system includes periodic flooding, time cover crops so that the paddy is not flooded when large amounts of fresh residue are present.
- Make compost from a diversity of organic materials with an overall C:N ratio between 25:1 and 40:1, and maintain aerobic conditions (*e.g.,* turn windrows).

See *Resources, items 1–5, 14, 15, 18, 24,* and *25* for tips on mitigating N_2O and CH_4 emissions from cropland; *item 6* for on-farm propagation of mycorrhizal inocula; and item 11 for SRI production methods. For more on managing N in organic systems, see *Soil Health and Organic Farming: Nutrient Management for Crops, Soil, and Environment.* For more on water management, see *Soil Health and Organic Farming: Water Management and Water Quality.*

Minimizing methane (CH_4) and net total GHG emissions in livestock operations

Although grass-fed ruminants emit more enteric CH_4 than grainfed (Manale, *et al.,* 2016), management-intensive rotational grazing (MIG) systems may sequester sufficient SOC to offset CH_4 and N_2O emissions, and higher forage quality may reduce enteric CH_4 (Wang, *et al.,* 2015; Rowntree, *et al.,* 2016; Stanley, *et al.,* 2018).

To mitigate net GHG emissions during organic livestock production:

- Maximize time on pasture and minimize time spent in confinement (reduces need for manure storage).
- Implement mob grazing, holistic management, adaptive multipaddock (AMP), or other MIG system, adapted to your region, climate, soils, pasture resources, livestock species and breeds, and farming or ranching system.
- Ensure sufficient rest periods for full recovery of pasture or range before regrazing. *This is critical for C sequestration, soil health, forage quality, and livestock nutrition.*

- Monitor and manage pasture/range for forage quality and livestock nutrition; modify grazing schedule and/or overseed desirable species as needed to improve forage quality.
- Arrange paddocks, watering areas, and rotation schedule to distribute manure evenly and minimize N_2O hotspots.
- Eliminate manure lagoon storage if possible.
- Compost or dry stack manure with sufficient dry, high-carbon bedding (straw, wood shavings, *etc.*) to achieve an initial C:N ratio of 25:1 or higher; turn windrows as needed to maintain aerobic conditions.
- If liquid manure storage is unavoidable, install a facility to capture CH_4 for use as fuel, or at least "flare" it (controlled burn) for release as less-harmful CO_2.
- Spread manure when soil is well drained and aerobic, not while saturated, frozen, or snow-covered.
- Apply manure at rates consistent with sound nutrient management, based on soil tests.

See *Resources, items 7–10, 14, 16, 17, 19–21,* and *23–25* for more information on estimating and managing GHG emissions in organic livestock production. *Items 10, 19, 21,* and *25* provide case studies of successful MIG systems from different regions across the U.S.

Building soil health for climate adaptation and agricultural resilience

Practices that enhance soil food web function, build SOC throughout the soil profile, or enhance nutrient cycling and nutrient efficiency, tend to improve crop and livestock resilience to pests, diseases, and abiotic stresses such as drought and unpredictable frost dates. So, don't wait for the farm GHG models to become more accurate or for carbon trading markets to open. Climate-friendly soil-building practices can help your farming system adapt to climate changes already under way, and may improve your economic bottom line in the long run.

See Resources, *items 7, 19–21,* and *23* for an overview of farm management strategies for climate adaptation, including farm stories that illustrate successful strategies.

Resources

1. **Greenhouse Gases and Agriculture: Where does Organic Farming Fit?** (Lynne Carpenter-Boggs, D. Granatstein, and D. Huggins, 2016). In-depth webinar on agricultural GHG emissions and opportunities for mitigation. *http://articles.extension.org/pages/30835/greenhouse-gases-and-agriculture:-where-does-organic-farming-fit-webinar*.
2. **Impact of Organic Grain Farming Methods on Climate Change** (Webinar by M. Cavigelli, USDA ARS Beltsville, MD, 2010). *http://articles.extension.org/pages/30850/impact-of-organic-grain-farming-methods-on-climate-change-webinar*.
3. **Why the Concern about Nitrous Oxide Emissions?** (C. Cogger and D. Collins, Washington State University, and A. Fortuna, North Dakota State University, 2014).
4. **Management to Reduce N_2O Emissions in Organic Vegetable Production Systems.** (A. Fortuna, D. Collins, and C. Cogger). Webinars 1 and 2 at: *http://articles.extension.org/pages/70280/two-partwebinar-series-on-greenhouse-gas-emissions-and-soil-quality-in-long-term-integrated-and-tra*.
5. **Soil Microbial Nitrogen Cycling for Organic Farms** (Louise Jackson, University of California, Davis, 2010). Describes how soil organisms regulate soil N retention, crop N nutrition, and N_2O emissions. *http://articles.extension.org/pages/18657/soil-microbial-nitrogen-cycling-for-organic-farms*.
6. **Soil Fertility in Organic Farming Systems: Much More than Plant Nutrition** (Michelle Wander, University of Illinois, 2015). N cycling and practical organic nutrient management. *http://articles.extension.org/pages/18636/soil-fertility-in-organic-farming-systems:-much-more-than-plant-nutrition*.
7. **On-farm Production and Utilization of AM Fungus Inoculum** (David Douds, Jr., USDA Agricultural Research Service, 2015). How to introduce and foster mycorrhizal fungi in organic fields. *http://articles.extension.org/pages/18627/on-farm-production-and-utilization-of-am-fungus-inoculum*.
8. **New Times, New Tools: Cultivating Climate Resilience on Your Organic Farm** (L. Lengnick, 2016). Climate change adaptation, including adaptation stories from leading organic farms across the U.S. *http://articles.extension.org/pages/73466/new-times-new-tools:-cultivating-climate-resilience-on-your-organic-farm*.
9. **Greenhouse Gas Emissions Associated with Dairy Farming Systems** (Tom Richard and Gustavo Camargo, Pennsylvania State University, 2011) Webinar comparing organic grass, organic grass/crop, conventional grazing, and confinement systems, and strategies to mitigate GHG. *http://articles.extension.org/pages/32626/greenhouse-gas-emissions-associated-with-dairy-farming-systems-webinar*.
10. **Carbon Farming.** Special supplement to *The Natural Farmer,* Winter 2016–17, 32 pp. Practical C sequestration strategies that organic farms in New England utilize, including cover cropping, rotational grazing, and reduced tillage in small scale vegetable production. *http://thenaturalfarmer.org/issue/winter-2016-17-carbon-farming/*.
11. **Grazing.** Special supplement to *The Natural Farmer,* Winter 2014–15, 32 pp. In-depth how-to information on management-intensive rotational grazing systems that sequester SOC and build soil, pasture, and herd health. Articles include *Mob Grazing,* Allen Savory's Holistic Management system, and several farmer articles on organic dairy cattle and lamb grazing systems. *http://thenaturalfarmer.org/issue/winter-2014/*.
12. **Crop Intensification.** Special supplement to *The Natural Farmer,* Winter 2013–14, 32 pp. Describes the System of Rice Intensification (SRI), a non-flooded approach to high-yield organic rice production developed in Madagascar in the 1980s, and implemented successfully in the U.S. and elsewhere. Compared to paddy rice, SRI builds soil and crop health, and sharply reduces CH_4 emissions. *http://thenaturalfarmer.org/issue/winter-2013/*.
13. **Biochar in Agriculture,** special supplement to the Fall, 2015 issue of *The Natural Farmer* includes a number of articles on the history, science, practical applications, potential C sequestration benefits, and eco-social pros and cons of biochar as a soil amendment. *http://thenaturalfarmer.org/issue/fall-2015/*.

14. Rodale Institute's Farming Systems Trial, *https://rodaleinstitute.org/our-work/farming-systems-trial/*
    a. *Farming Systems Trial Brochure.* Summary after 35 years. 2015, 2 pp. *http://rodaleinstitute.org/assets/FST-Brochure-2015.pdf*.
    b. *The Farming Systems Trial, Celebrating 30 Years.* 2011, 21 pp. *http://rodaleinstitute.org/assets/FSTbookletFINAL.pdf*.
    c. *Regenerative Organic Agriculture and Climate Change: a Down to Earth solution to Global Warming.* 2014, 16 pp. White paper based on Rodale's farming systems trial and other farming systems trials around the world. *https://rodaleinstitute.org/assets/RegenOrgAgricultureAndClimateChange_20140418.pdf*.
    d. *Reversing Climate Change Achievable by Farming Organically.* Blog post at *https://rodaleinstitute.org/reversing-climate-change-achievable-by-farming-organically/*.
15. **Denitrification-Decomposition (DNDC) Calculator,** developed by Institute for the Study of Earth, Oceans, and Space at University of New Hampshire, includes modules for estimating GHG emissions in farming systems across the U.S. (US–DNDC Model), in livestock production (Manure-DNDC Model), and in forestry (Forest-DNDC Model). Models are updated periodically. *http://www.dndc.sr.unh.edu/*.
16. **Organic Farming Footprint (OFoot),** developed by Center for Sustaining Agriculture and Natural Resources at Washington State University, aims to provide organic farmers, certifiers, and carbon traders with a scientifically sound yet simple estimate of C and N sequestration and net GHG balance for a given organic cropping scenario. Tool is available at *https://ofoot.wsu.edu/*, with additional information at *http://csanr.wsu.edu/organic-farming-footprints/*. The project has also updated the CropSyst model to support water and nutrient management of 28 additional crops. *http://sites.bsyse.wsu.edu/cs_suite/cropsyst/documentation/articles/description.htm*.
17. **Shades of Green Dairy Farm Calculator** (Charles Benbrook, The Organic Center, 2014). Webinar offers instruction on the use of this GHG footprint calculator for dairy farms, and discusses the reasons for wildly inconsistent outcomes of GHG studies. *http://articles.extension.org/pages/31790/shades-of-green-dairy-farm-calculator-webinar*.
18. **Northeast Dairy Emissions Estimator (NDEE),** is an on-line tool to help dairy producers in New York and New England estimate GHG emissions from all parts of the farm operation, and evaluate tactics to reduce GHG. *http://nedairy.ags.io/*.
19. **GoCrop** is an online nutrient management planning tool developed by University of Vermont. *http://gocrop.com/*. University of Illinois is refining modules for estimating plant available nitrogen and GHG emissions for organic systems.
20. **Two Percent Solutions for the Planet: 50 low-cost, low-tech, nature-based practices for combating hunger, drought, and climate change** (Courtney White, Quivira Coalition, *www.quiviracoalition.org*. 2015. Chelsea Green Publishing, White River Junction VT, 227 pp.). Farmers, ranchers, conservationists, and food system activists share their stories and practical solutions to mitigate climate change, sequester carbon, and build resilient and abundant agricultural and food systems.
21. **The Soil will Save Us: how scientists, farmers, and foodies are healing the soil to save the planet** (Kristin Ohlson, 2014. Rodale Press, *http://rodalebooks.com*, 242 pp.). Journalist Kristin Ohlson interviews leading scientists in sustainable agriculture and presents the science of soil C sequestration and soil health in plain English.
22. **Soil Health, Water & Climate Change: a Pocket Guide to What You Need to Know.** (Land Stewardship Project, October 2017, *http://landstewardshipproject.org/smartsoil*, 51 pp.). Although not specifically geared towards organic systems, this Pocket Guide offers valuable practical information on conservation agriculture and management intensive rotational grazing practices for soil health, water quality, and C sequestration in the Midwest. The Guide also discusses impacts of climate disruption on agriculture and the urgent need—and opportunities—to build system resilience to weather extremes.

23. **NRCS Web Soil Survey,** *https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm*. Enter your full mailing address to locate your fields and identify your soil types and their properties including texture, depth, profile, drainage, topography, production capability, and constraints.
24. **NRCS Conservation Stewardship Program (CSP),** *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/*. The CSP offers technical and financial support for farmers and ranchers in adopting a whole-farm approach to resource stewardship that can enhance productivity and build resilience to weather extremes. CSP offers a menu of conservation enhancements including many that enhance SOC accrual, and some that are designed specifically for organic systems.
25. **Organic Agriculture Resource Area on the Extension website** *http://articles.extension.org/organic_production*. Articles, webinars, videos, courses on many aspects of organic vegetable, grain, and dairy production and marketing, developed by the eOrganic Community of Practice.
26. **ATTRA—National Sustainable Agriculture Information Service,** *https://attra.ncat.org/*. Offers publications, videos, and webinars on a wide range of topics; an Ask an Ag Expert service by phone or online; breaking research news and new information resources; and a search function that facilitates information retrieval on topics such as organic no-till or enterprise budgets. Some topic areas with substantial offerings include:

    a. Organic farming *https://attra.ncat.org/organic.html*.

    b. Marketing, business, and risk management *https://attra.ncat.org/marketing.html*.

    c. Urban agriculture *https://attra.ncat.org/urban_ag.html*.

    d. Soils and compost *https://attra.ncat.org/soils.html*.

Organic Farming, Soil Health, Carbon Sequestration, and Greenhouse Gas Emissions: A Summary of Recent Research Findings

Research continues to validate the four NRCS principles of soil health as guidelines for SOC sequestration, climate mitigation and adaptation. The National Organic Standards require organic producers to implement these principles (see *Concept #3* on page 27), using practices to *keep the soil covered, maintain living roots,* and *increase biodiversity* that non-organic conservation farmers also use routinely. As noted earlier, organic producers must take a different approach to the fourth principle to *minimize soil disturbance,* as the Organic Standards exclude synthetic fertilizers and herbicides, and require the use of organic and natural mineral nutrient sources.

Following are a few highlights from recent research findings on organic and sustainable agriculture, soil health, C sequestration, and climate mitigation and adaptation.

Agricultural carbon sequestration and climate mitigation[:]

- Protecting the world's agricultural soils from erosion would reduce GHG emissions by ~1.1 billion tons CO_2-Ceq per year, or 7% of humanity's total annual GHG (Lal, 2003).
- Worldwide implementation of NOP requirements to "maintain or improve soil organic matter" would check the net decline in global SOC pools and thereby save 2 billion tons C/year, about 12% of total annual GHG (Harden, *et al.,* 2018).

Growing SOC in place: diversifying and intensifying the crop rotation[:]

- In long-term trials, organic grain rotations have accrued 400–600 lb SOC/acyear more than conventional grain rotations, primarily through *higher crop diversity* (*e.g.,* three annual grains and a perennial forage *versus* corn-soy, Cavigelli, *et al.,* 2013; Delate, *et al.,* 2015b), and *greater mean duration of living plant cover* (*e.g.,* 72% *vs.* 42% of the calendar year, Wander, *et al.,* 1994).
- Organic orchards managed with living orchard floor cover have double the SOC levels of orchards maintained by clean tillage or herbicide fallow (Lorenz and Lal, 2016).
- Removing annual crop residues (*e.g.,* corn stover for biofuel) severely depletes SOC and increases erosion risks (Blanco-Canqui, *et al.,* 2016a, 2016b)
- In semiarid regions, alternate year fallow (*e.g.,* in dryland wheat) causes significant losses of SOC, even under no-till management, whereas planting one crop per year can sustain SOC levels (Halvorson, *et al.,* 2002; West and Post, 2002).

Growing and holding SOC in place: the central role of soil life:

- Organic practices that build soil microbial activity and biodiversity, generally enhance PO_XC (index of SOC stabilization) and PMC (SOC mineralization). PO_XC and PMC are better predictors of crop yields than other SOC fractions (Hurisso, *et al.,* 2016).

- Short-term increases in microbial biomass, microbial activity, and active SOC generally foretell longer-term increases in total SOC (Ghabbour, *et al.,* 2017; Lori, *et al.,* 2017).
- Cover crops with compost or manure applications may build more SOC and microbial functional biodiversity than either practice alone (Delate, *et al.,* 2015a, Hooks, *et al.,* 2015).
- As crop diversity increases from monoculture or corn-soy to four or five crops, microbial biomass, and functional diversity increase substantially (Tiemann, *et al.,* 2015).
- Reduced tillage (shallow ~3″, or non-inversion chisel plow) can improve microbial biomass and function in organic systems (Sun, *et al.,* 2016, Zuber and Villamil, 2016).
- Increased microbial respiration *per unit microbial biomass* (metabolic quotient) may indicate stresses on the soil biota, such as bare fallow, intensive tillage, or excessive soluble N (Fauci and Dick, 1994; Lori, *et al.,* 2017; Zuber and Villamil, 2016).
- Plant root symbiotic arbuscular mycorrhizal fungi (AMF) play a major role in nutrient cycling and transmuting plant organic C into stable SOC (Hamel, 2004; Rillig, 2004).
- Many cover crops, including oats, rye, sorghum, sunnhemp, and bahiagrass, host AMF and increase soil AMF populations (Douds, 2015; Duncan, 2017; Finney, *et al.,* 2017).
- AMF are deterred by tillage, fallow periods, and excessive soil P levels, which may occur with heavy use of compost or manure (Rillig, 2004).
- In-row subsurface drip irrigation can enhance water use efficiency and yield in organic tomato in low-rainfall regions, but leaving interrow soil unwatered can reduce microbial activity and SOC sequestration (Schmidt, *et al.,* 2018).

Sequestering C in perennial conservation plantings[:]

- The NRCS Conservation Reserve Program (CRP), which converts degraded, marginal, or environmentally sensitive cropland to perennial grass or woodland has been estimated to sequester 3,200 lb C/ac annually in SOC and aboveground biomass (Manale, *et al.,* 2016).

- Permaculture home gardens planted on previously "under-utilized" land, and replanting degraded cropland to forest can accrue over 3,000 lb SOC/ac-year (Feliciano, *et al.,* 2018).

SOC saturation: how much C can the land hold?

- Restoration of global SOC to pre-agriculture levels (~8,000 BC) may be achievable with further advances in soil health management, and would absorb about 34 years' worth of total global human-caused GHG emissions at current rates (Lal, 2016).

Looking below the surface: the hidden value of deep roots[:]

- While most soil biological activity and nutrient release occurs in the top 12″, at least ½ of all SOC exists *below* 12″ (Brady and Weil, 2008; Lal, 2015).
- Deep SOC is deposited mainly by plant roots, and long-term SOC accrual correlates closely with root biomass (Brady and Weil, 2018; Kell, 2011; Rasse, *et al.,* 2005).
- Many crops send roots 4′ to 8′ deep if soil conditions allow it. Cover crops such as pearl millet, sorghum-sudangrass, sunflower, sunnhemp, radish, and winter rye penetrate subsurface hardpan and facilitate deep rooting by subsequent crops (Rosolem, *et al.,* 2017).
- Organic practices can enhance cereal grain root biomass up to 60 percent (Hu, *et al.,* 2018).
- Managing for deep, extensive root systems, including plant breeding, may be a major opportunity for SOC sequestration, climate mitigation, and resilience (Kell, 2011).

Soil inorganic carbon: an important unanswered question[:]

- Soils of prairie, semiarid, and arid regions hold 20–90% of their total carbon in the form of carbonates (soil inorganic carbon or SIC) (Brady and Weil, 2008).
- Recent research has documented significant management impacts on SIC, including SIC losses in organic systems in three out of seven organic-conventional comparisons.
- More research on SIC management in drier regions is needed (Lorenz and Lal, 2016).

Reducing soil disturbance: tillage[:]

- Organic rotations with cover crops, compost or manure, and routine tillage often sequester as much C as conventional no-till (Syswerda, *et al.,* 2011; Wander, *et al.,* 2014).
- In one long-term trial, the organic system accrued 400 lb/ac-year *more* SOC than continuous conventional no-till (Cavigelli, *et al.,* 2013).
- Practical reduced-till options for organic producers include ridge tillage, spading machine, chisel plow, rotary harrow (shallow till), and sweep-plow undercutter to terminate cover crops (Schonbeck, *et al.,* 2017).
- Compared to plow-disk or rototiller, terminating cover crops with spader or undercutter can reduce compaction and improve yields (Cogger, *et al.,* 2013; Wortman, *et al.,* 2016).

Reducing soil disturbance: organic *versus* conventional inputs[:]

- Long-term use of soluble NPK fertilizers has depleted deep (12–18″) SOC and total soil N in the 100+ year Morrow Plots (University of Illinois) and many other long-term trials around the world (Khan, *et al.,* 2007).

- Regular or heavy use of inorganic N can reduce microbial biomass, increase metabolic quotient, and compromise nutrient cycling and soil food web function (Fauci and Dick, 1994).
- Organic nutrient sources supported greater SOC accrual and AMF activity than inorganic (soluble) fertilizers (Zhang, *et al.,* 2016).

Compost, manure, and other organic amendments[:]

- In a meta-analysis of 74 farming system studies, crop-livestock integrated organic systems that use on-farm manure and compost accrue ~240 lb SOC/ac-year) without relying on imported organic inputs (Gattinger, *et al.,* 2012).
- The percent of applied organic C retained as stable SOC is generally greatest for finished compost, followed by solid manure, uncomposted plant residues, and liquid manure (slurry) or liquid biogas digestate (in that order). (Cogger, *et al.,* 2013; Hurisso, *et al.,* 2016; Sadeghpour, *et al.,* 2016; Wuest and Reardon, 2016).
- One ton of finished compost may add ~220 lb stable SOC, but GHG emissions (primarily CH_4) during compost production have been estimated at 400 lb CO_2-Ceq per ton (Carpenter-Boggs, *et al.,* 2016). This analysis did not include offsets from diverting organic materials from landfills or manure lagoons.
- A single compost application (total N 225 lb/ac) to grasslands in a California study stimulated plant production and enhanced "ecosystem C storage" (soil + biomass C) by 25–70% over a 3 year period (Ryals and Silver, 2013).
- A single application of composted cattle manure (22 tons dry weight/ac) to a dryland wheat field in Utah enhanced wheat yields for 15 years, at the end of which SOC in the top 4″ was double that in an adjacent unamended field (Reeve and Creech, 2015).

Biochar[:]

- The biochar method is based on findings that up to ½ of the SOC in fertile prairie soils is "black carbon" left by prairie fires, and that charcoal from indigenous peoples' cooking fires helped create the anomalously fertile *terra preta* soils in the Amazon basin, where the native soils are nutrient-poor (Kittredge, 2015; Wilson, 2014).

- Biochar can stabilize SOC, improve soil aggregation and moisture retention, enhance nutrient availability, and improve crop yields. Results vary widely, and biochar works best in conjunction with compost or microbial inoculants (Blanco-[C]anqui, 2017; Kittredge, 2015; Wilson, 2014).
- As biochar ages for several years in the soil, it acquires cation exchange capacity, binds to soil clays, and stabilizes SOC more effectively (Mia, *et al.,* 2017).
- Sustainability concerns include removal of plant biomass to create biochar, land grabs in the Global South for biochar feedstock, and GHG emissions during pyrolysis (North, 2015).
- Annual spring burning enhanced root biomass and AMF activity in a Kansas native tallgrass prairie, suggesting that prescribed burning might yield some of the benefits of biochar without the need for off-farm inputs (Wilson, *et al.,* 2009).

Nitrous oxide emissions from cropland soils[:]

- Soil N_2O emissions are related to soil moisture, soluble N, and labile organic C; N_2O emissions are minimal when soil nitrate-nitrogen (NO_3-N) is below 6 ppm, or soil moisture is below field capacity (Cai, *et al.,* 2016; Thomas, *et al.,* 2017).

- N_2O emissions are directly related to impeded gas diffusion through the soil, and are therefore related to high soil moisture, fine (clayey) texture, and soil compaction (Balaine, *et al.,* 2016; Charles, *et al.,* 2017).
- N_2O emissions may increase in no-till if roll-crimped covers maintain soil moisture levels above field capacity (Linn and Doran, 1984).
- In conventional corn production, N_2O emissions rise sharply as rates of fertilizer N begin to exceed crop needs (Eagle, *et al.,* 2017; Millar, *et al.,* 2010).
- Peak N_2O emissions occur when rains follow soluble N applications in conventional agriculture, and after legume-rich cover crops or sod are plowed down in organic systems (Burger, *et al.,* 2005; Han, *et al.,* 2017; Westphal, *et al.,* 2018).
    - Red clover sod can contain 300 lb N/ac, with 85% of it below ground. A legume-grass sod is recommended for grain-forage rotations because it may emit less N_2O at plowdown than an all-legume sod (Han, *et al.,* 2017).
    - In a meta-analysis and modeling study including 8,000 sites throughout Europe, adding legume cover crops to existing rotations (clover planted in any fallow period ≥2 months) was estimated to sequester about 3 tons SOC/ac over 80 years, but also to emit twice that amount of N_2O in CO_2-Ceq (Lugato, *et al.,* 2018).
- Studies on N_2O emissions from organic systems illustrate the need for careful management of organic N, and for more research. For example:
    - In Colorado organic lettuce trials, reducing preplant N (feather or blood meal) from 50 to 25 lb/ac cut N_2O emissions by ⅔ without affecting yield. Delivering the N in five split applications via drip fertigation (fish emulsion) during crop growth eliminated N_2O emissions altogether (Toonsiri, *et al.,* 2016).
    - In California, N_2O emissions from organic tomato systems were ½ those from conventional tomato systems (Burger, *et al.,* 2005).
    - Some California tomato fields under long-term organic management exhibit "tight N cycling," in which plant-soil-microbe dynamics and expression of plant N uptake genes maintain low soil soluble N, yet adequate plant nutrition and high yields. These fields receive diverse low- and high-C:N organic inputs, and have high active and total SOC levels (Jackson, 2013; Jackson and Bowles, 2013).
    - Organic broccoli in California and Washington required more than 200 lb N/ac for optimal yield. Providing it with legume green manure + organic fertilizers released 11–27 lb N/ac-year as N_2O, which negates 1,400–3,400 lb/ac SOC sequestration (Collins and Bary, 2017; Li, *et al.,* 2009).
    - An organic grain rotation in Michigan fertilized with poultry litter (130–200 lb N/ac-year) emitted five times as much N_2O per year as the conventional system, mostly during intense bursts after heavy rains (Baas, *et al.,* 2015).

- Indirect emissions take place when NO_3-N is leached from the soil profile and a portion (estimated by IPCC at 0.75%) is converted to N_2O off site (Parkin, *et al.,* 2016).
  - Deep rooted cover crops like sorghum, millets, radish, and chicory scavenge NO_3-N, thus curbing indirect N_2O emissions (Rosolem, *et al.,* 2017).
  - Pearl millet, sorghum, groundnut, and signalgrass, release natural nitrification inhibitors that reduce NO_3-N leaching and N_2O emissions (Rosolem, *et al.,* 2017).
- Active AMF can promote tight nutrient cycling and reduce N_2O provided that soil P levels are not excessively high (Hamel, 2004; Hu, *et al.,* 2016).
- Lab trials suggest that biochar may help curb N_2O emissions (Cai, *et al.,* 2016).

Methane emissions in rice production[:]

- Paddy (flooded cultivation) rice can release 110 lb CH_4-C/ac per cropping cycle (~840 lb CO_2-Ceq), and emissions increase when a cover crop is terminated prior to flooding or organic N fertilizer is applied (Dou, *et al.,* 2016).
- While flooded rice shows severe root decay by the time the crop flowers, roots of SRI (non-flooded) rice remain healthy, grow larger and deeper, host AMF and beneficial soil bacteria, and enhance nutrient use efficiency (Thakur, *et al.,* 2016).

Sequestering C and minimizing GHG emissions in organic livestock production[:]

- Higher enteric CH_4 and lower milk production in grass-fed organic dairy cows double direct GHG emissions per gallon of milk compared to conventional confinement dairy (Richard and Camargo, 2011). However, this comparison does not consider potential SOC sequestration under management intensive grazing (MIG).
- Compared to continuous grazing in the cow-calf phase of beef production in the Southern Great Plains region of Texas, multipaddock grazing enhanced SOC sequestration by 2,400 lb/ac annually for 10 years, improved forage quality, and thereby reduced enteric CH_4 about 30%, resulting in a net negative GHG footprint (Wang, *et al.,* 2015).
- In Michigan, conversion of grass-finishing beef operations from continuous grazing to adaptive multi-paddock grazing sequestered 3,200 lb C/ac annually for 4 years, and reduced enteric CH_4 by 36%, again resulting in a net GHG sink (Stanley, *et al.,* 2018).
- In coastal South Carolina, converting depleted sandy loam (0.5% SOC) from row crops to Bermuda grass pasture under MIG accrued 6,300 lb C/ac annually during the third through sixth year, after which annual SOC accrual tapered off (Machmuller, *et al.,* 2015).
- Producer success stories with MIG abound from across the U.S.; before and after photos show dramatic soil and forage health outcomes from MIG. One farm in upstate New York documented SOC gains well over 3 tons/ac in 3 years through dozens of soil tests. (Kittredge, 2014–15).
- Crop-livestock integration can enhance SOC, improve nutrient cycling, and mitigate GHG emissions. While baling-off cover crops or corn residues reduces SOC and promotes erosion, these resources can be grazed without seriously compromising soil health (Blanco-Canqui, *et al.,* 2016a, 2016b; Franzluebbers and Studeman, 2015).

Breaking the vicious cycle: positive feedback between greenhouse gases and climate change[:]

- Warming temperatures will accelerate SOC decomposition; for example, models indicate that, with continued warming, no-till corn fields in Ohio that are currently sequestering C will begin losing SOC before the end of the century (Maas, *et al.,* 2017).
- Impacts will be most severe in cold climates (a 10% SOC loss for every 1.8 °F increase), and less pronounced in tropical regions (3% loss per 1.8 °F) (Kirschbaum, 1995).
- Thawing of permafrost may lead to an additional 600 million tons SOC loss per year globally, a 30% increase over current net SOC loss (Hardin, *et al.,* 2018).
- Fall tillage combined with warmer, drier winters and springs leaves Corn Belt soils in an excessively "fluffy" condition that hinders seed-soil contact and stand

establishment, leading to further SOC losses to erosion (Daigh and DeJong-Hughes, 2017).

- Soil N_2O emissions are directly related to soil temperature, and thus may increase as climates warm. In a meta-analysis of 27 studies across the Corn Belt, N_2O emissions increased 18–28% with every 1.8 °F increase in mean July temperatures (Ball, *et al.,* 2007; Eagle, *et al.,* 2017).
- Rising atmospheric CO_2 levels may directly accelerate SOC losses. In Florida, scrub oak lands experimentally subjected to elevated CO_2 lost SOC even as tree growth increased (Petit, 2012).
- Experimental CO_2 enrichment of grazing lands increased fungal biomass and N_2O emissions, an unexpected finding given the role of mycorrhizal fungi in mitigating N_2O (Rillig, 2004; Zhong, *et al.,* 2018).
- No-till based conservation systems that store SOC near the surface may not suffice in the face of these trends; new, innovative approaches, such as integrated organic systems and deep SOC sequestration, will be needed to break the vicious cycle (Kell, 2011).

Questions for Further Research: Organic Farming Soil Carbon, Soil Health, and Climate

Findings to date suggest that widespread adoption of sustainable organic production systems could make the world's agriculture climate-neutral, and enhance the resilience of farms and ranches to the impacts of climate changes already underway. Multiple studies and meta-analyses on organic systems have validated the National Organic Standards and the NRCS Four Principles of Soil Health Management as frameworks for climate-friendly and adaptive farming and ranching. In addition, researchers have identified some promising new strategies that merit further research and development into practical guidelines for producers. However, several major hurdles to realizing the vision of soil- and climate-friendly agricultural systems remain, including:

- A need for tools to help producers and service providers translate framework principles into effective, economically viable, site-specific applications.
- A need for practical tools that farmers can use to measure SOC, estimate GHG emissions, and monitor progress toward soil health and climate goals.
- A need for crop cultivars and livestock breeds that will thrive and yield well in sustainable organic production systems.
- Knowledge gaps in areas such as soil microbial community dynamics, the nature of stable SOC, and the coupling of C and N cycles in the agroecosystem.
- A need to address economic, logistical, policy, and social barriers to farmer adoption of soil health and climate mitigation practices.

Putting principles into practice

Several pivotal strategies appear to offer substantial and fairly consistent benefits to soil health, SOC sequestration, climate mitigation, and agricultural resilience:

- Crop intensification—maximizing plant biomass and year round soil coverage.
- Maximizing living roots—root biomass, depth, duration, diverse root architecture.
- Diversified crop rotation—production crops, cover crop mixes, perennial sod phase.
- Reducing soil disturbance—physical (tillage, traffic), chemical (inputs), and biological (overgrazing, invasive exotic species).
- Integrated organic soil and crop management: diverse rotation + cover crops + organic amendments + nutrient management + soil-friendly tillage practices.
- Management-intensive rotational grazing for livestock systems.
- Crop-livestock integration.

In implementing these strategies on their farms, organic producers must learn new skills and consider new costs (*e.g.,* cover crop seed, planting equipment for new crops), risks (*e.g.,* weed pressure and potential yield reductions in reduced tillage systems), and income foregone (*e.g.,* adding a sod break to an intensive vegetable rotation). There are potential economic benefits as well, ranging from new crop or livestock enterprises to long-term improvements in soil health, fertility, and resilience. Farmers may have questions such as:

- What are the most cost-effective and least risky practices to increase crop biomass, soil coverage, and living roots in my crop rotation?

- How can I ensure that new crops added to the rotation will be profitable?
- What are the best cover crops for my farm and crop rotation?
- When and how should the cover crops be terminated?
- How can I minimize N_2O emissions upon plowing-down the sod phase of the rotation?
- How much compost should I apply?
- What are the most practical and least risky ways to reduce tillage intensity?

The answers to these questions depend so much upon site specific factors—climate, soil, topography, farming system, crop and livestock mix, markets, *etc.,* that research cannot yield prescriptive answers for all producers. In addition, solutions developed in collaboration with farmers engaged as equal partners are much more readily adopted than formulae developed and delivered in a top-down manner. Research outcomes that could help organic producers implement soil-building, climate-friendly, and profitable management practices include:

- Tools to help the farmer select the best system components (crop rotation, cover crops, organic fertilizers and amendments, tillage tools and techniques, etc) for their climate, soil, production system, and market constraints and opportunities.
- A process similar to the NRCS's Comprehensive Conservation Planning that farmers and service providers can use to develop the best site-specific strategies to meet identified production, soil health, and climate mitigation/adaptation goals.
- Farm case studies and success stories in soil health, C sequestration, and climate adaptation.
- Enterprise budgets and business planning templates to help producers evaluate the economic viability of current and potential new crops in a diversified rotation.
- Economic analysis and risk management tools to help producers evaluate the potential costs and benefits of adopting a new system or practice.

Monitoring SOC, soil N, GHG, and progress toward soil and climate goals

Farmers need practical tools to monitor soil health and fertility, and the GHG footprint of their production systems. These include simple, reliable tests that can be conducted on site or by a standard soils lab for a modest fee, and user-friendly computer models and decision tools that provide output that is relevant for organic systems. Most soil test labs estimate total SOM by loss on ignition, a few labs offer PO_XC (index of SOC stabilization) and PMC (SOC mineralization), and several research teams have developed experimental protocols for estimating the release of plant-available N via SOC mineralization. Additional research is needed to:

- Develop improved sampling and testing protocols for accurate and meaningful measurement of total SOC, which usually accounts for about 58% of SOM.
- Develop practical sampling and testing protocols for monitoring subsurface SOC beyond the normal sampling depths of 6″ to 12″.
- Develop benchmarks and realistic site-specific goals for total SOC based on climate (temperature and rainfall regimes), soil type and texture, and production system.
- Verify and demonstrate a simple in-field soil nitrate-N test as a N monitoring and management tool in organic production (Collins and Bary, 2017).
- Develop reliable, practical methods to estimate plant-available N released through SOC mineralization.
- Make practical, reliable on-farm monitoring of PO_XC, PMC, and other measures of soil microbial activity and SOC fractions widely available and affordable.
- Complete development of OFOOT and organic modules for tools such as DNDC and COMETFarm, so that organic producers can estimate soil N_2O emissions, enteric CH_4, and net total GHG of their farming system, and identify mitigation opportunities.

Plant and animal breeding for SOC sequestration, GHG mitigation, and resilience in organic farming

Development and release of public crop cultivars and livestock breeds that thrive and perform well in sustainable organic production systems could enhance organic farmers' yields, and thereby reduce the GHG footprint per unit output for organic farm products. New cultivars and breeds that combine this capacity with desired market traits (flavor, nutritional quality, *etc.*) will improve organic producers' bottom line and increase their capacity to implement climate-friendly soil health management practices. Farmer participatory plant breeding, in which producers work with plant breeders to identify objectives, conduct on-farm breeding and selection, and produce seed, have proven cost-effective in making new, improved cultivars available to farmers (Schonbeck, *et al.,* 2016). In addition, certain plant breeding objectives based on known heritable traits can contribute *directly* to SOC sequestration, GHG mitigation, and resilience. These include:

- Nutrient use efficiency, tight N cycling, capacity to thrive in soils low in soluble N.
- Enhanced rhizosphere interaction with mycorrhizal fungi, N fixing bacteria, and other beneficial soil biota that facilitate plant nutrition, vigor, and resilience.
- Water use efficiency.
- Resilience to drought, excessive moisture, temperature extremes, and other stresses.
- Capacity to maintain normal production despite reduced or unpredictable chill-hours and frost dates resulting from climate change (perennial fruit and nut crops).
- Deep, extensive, high biomass root systems.
- Enhanced total biomass, increased plant residue return to the soil while maintaining yield, market qualities, and ease of harvest.

Climate related livestock breeding objectives might include:

- Capacity to thrive in management-intensive rotational grazing (MIG) systems.
- Reduced enteric methane production in ruminants.
- Increased resilience to heat and other weather extremes.

Developing promising leads into practical applications

Soil health research over the past 10 years has identified several new strategies that show potential to enhance agricultural SOC sequestration or GHG mitigation. Some are based on one or a few studies, and merit further testing in a diversity of regions, soils, climates, and organic production systems, to evaluate their potential for practical application. Others have a more substantial track record in research, and need fine-tuning, demonstration, and outreach to facilitate more widespread and successful adoption. Promising new strategies and associated research priorities include:

- *Tight nitrogen cycling:* Identify practical methods to promote tight N cycling and N use efficiency in a wider range of organic vegetable, fruit, and grain crops, across a wider range of soils, climates, and regions (Jackson, 2013; Jackson and Bowles, 2013).
- *System of Rice Intensification:* Refine, evaluate, and demonstrate SRI for yield and GHG mitigation in organic rice in U.S. rice growing regions (Thakur, *et al.,* 2016).
- *Deep roots, soil health, and climate:* Explore the potential of deep rooted crops and organic practices to enhance deep SOC sequestration and N recovery; develop and demonstrate practical applications (Hu, *et al.,* 2018; Kell 2011; Rosolem, *et al.,* 2017).
- *Compost for grazing lands:* Determine whether the multi-year gains in forage biomass and SOC from a single compost application in California grasslands can be replicated in other regions, soils, and climates (DeLonge, *et al.,* 2013; Ryals and Silver, 2013).
- *Prescribed burning for* ***in-situ*** *biochar:* Conduct trials on grazing lands in different regions and climates to determine whether prescribed fire generates *in situ* biochar and benefits soil food web function and root growth as observed in Kansas (Wilson, *et al.,* 2009).
- *Forage quality and livestock GHG mitigation:* Verify and demonstrate efficacy of MIG in reducing ruminant enteric CH_4 emissions through improved forage quality on grazing lands in different regions across the U.S. (Stanley, *et al.,* 2018; Wang, *et al.,* 2015).

Addressing key knowledge gaps

Additional research is needed to better understand soil C and N dynamics and soil-plant-microbe interactions as they influence soil fertility, C sequestration, and GHG emissions in organic systems. For example, the chemical nature and sequestration mechanisms of "stable" SOC remain unclear, and sharply contrasting conceptual models of SOC-related processes have been proposed (Ghabbour, *et al.,* 2017; Lehman and Kleber, 2015; Six, *et al.,* 2002). Similarly, since organic N sources release plant available N through biological processes, their impacts on soluble soil N levels and N_2O emissions are more challenging to predict and manage than conventional fertilizer N (Charles, *et al.,* 2017). Research-based N recommendations for organic production are not available for many crops, and research-based estimates vary from as little as 25 lb N/ac to optimize organic lettuce yields (Toonsiri, *et al.,* 2016) and 20–40 lb/ac to replace N removed in mixed vegetable harvests (Wander, *et al.,* 2015), to >200 lb/ac to optimize organic broccoli yields (Li, *et al.,* 2009; Collins and Bary, 2017).

GHG impact analyses for organic practices can give widely different outcomes depending on the factors included in the analysis. For example, the composting process has been reported to emit more GHG (in CO_2-Ceq) than is sequestered as stable C in the compost itself; yet, composting can prevent much larger emissions by diverting organic materials from waste streams (Carpenter-Boggs, *et al.,* 2016; DeLonge, *et al.,* 2013). The direct GHG emissions of organic grassfed cattle have been estimated at double those from conventional confinement, yet total GHG footprint of grassfed livestock can become negative (net mitigation) based on rapid SOC sequestration during the first few years after implementation of MIG (Richard and Camargo, 2011; Stanley, *et al.,* 2018). However, composting and landfill are not the only two possible fates of organic "wastes," and the initial rapid increase in SOC under MIG levels off after the first decade. Thus, the full climate implications of these practices merit further study.

Priorities for additional research on soil, GHG, and climate in organic production include:

- Mechanisms of SOC stabilization and de-stabilization, and potential impacts of warming climates, tillage, fertility inputs, and other management practices on long-term SOC sequestration (Grandy, *et al.,* 2006; ITPS, 2015; Lehman and Kleber, 2015).
- Realistic estimates of total SOC sequestration from improved practices, taking into consideration climate, soil type and texture, and production system.
- Roles of soil bacteria, mycorrhizal fungi, nematodes, plant roots, and other soil food web components in soil C and N dynamics, SOC accrual, and GHG emissions.
- Efficacy of microbial inoculants (produced on-farm or commercial products) for soil health, climate mitigation, and adaptation.
- Impacts of inherent soil properties (soil series, texture, horizons, drainage, mineralogy, natural hardpans, *etc.*), on C and N cycling, soil-plant-microbe dynamics, and response of SOC and GHG emissions to organic management practices.
- Best management of organic N inputs for soil health, plant nutrition and N_2O mitigation:
    - N sources—compost, manure, organic N fertilizers, and legume cover crops.
    - Potential to mitigate N_2O emissions from green manure plowdown by using grass-legume mixtures *in lieu of* all-legume, and non-tillage termination methods.
    - Placement and timing—preplant broadcast or band, or in-row drip fertigation.
    - Application rates—establish optimum N rates for a wide range of crops, based on trials in organic fields in different regions, climates, and soil.
- Life cycle GHG analyses of compost production and application, including:
    - Comparison of composting with direct land application of uncomposted residues, as well as with GHG-intensive waste disposal (landfills, manure lagoons).
    - Best management practices for composting processes, and GHG impacts of variations from optimum starting C:N ratios, aeration/windrow turning schedules, and moisture management.
- Optimum compost use rates, considering soil nutrient levels, direct costs and benefits, and potential synergism between cover crops and compost on SOC [sequestration].
- Life cycle GHG analysis of biochar manufacture and use.

- Best irrigation practices, including potential tradeoffs between N_2O mitigation and reduced SOC sequestration under in-row drip fertigation (Schmidt, *et al.,* 2018; Toonsiri, *et al.,* 2016).
- Impacts of organic inputs and management practices on soil inorganic carbon (SIC) in soils of drier regions (Lorenz and Lal, 2016).
- Life cycle GHG analyses for MIG systems for organic beef, dairy, and other livestock, conducted over time spans beyond the initial period of rapid SOC sequestration after conversion from cropping or continuous grazing to MIG.
- Additional strategies to mitigate enteric CH_4 in organic livestock, including forage species composition, and NOP-allowed dietary supplements.

Overcoming socioeconomic, logistical, cultural, and policy barriers to adoption of climate-friendly organic farming practices

Farmers face significant economic, social, cultural, and policy barriers to adopting soil- and climate-friendly production systems. For example, many of the practices discussed here entail up-front costs, and economic benefits arising from improved production and resilience or reduced input needs may not begin to accrue for several years. Given the great variability in soil-crop-livestock-climate interactions, and the current lack of political support for climate mitigation, financial support through carbon markets or carbon offset payments does not appear feasible at this time.

While socioeconomic and policy issues were beyond the immediate scope of the research review on which this Guide is based, it has become clear that several key constraints and missed opportunities must be addressed before the potential for organic agriculture to mitigate GHG emissions and build agricultural resilience can be fully realized. These include:

- Lack of educational resources and qualified technical assistance to help organic farmers learn and successfully adopt new soil health and climate mitigation practices while maintaining or improving their bottom line.
- Actual and perceived risks associated with new practices, including the costs of acquiring new skills, equipment, and infrastructure, and lack of carbon markets or other cost offset for ecosystem services.
- Crop insurance and government farm policies that create disincentives to adopting conservation practices, such as cover cropping and diversified crop rotations.
- Social and cultural forces that deter adoption of new sustainable practices, including peer pressure and social norming in farming communities, as well as a pervasive political climate hostile to climate change mitigation science and action.
- Current agricultural and food system infrastructure, markets, and government policies that perpetuate the segregation of U.S. agriculture into livestock production within confined animal feeding operations (CAFOs), commodity grains (corn-soy-wheat), and specialty crops; lack of informational, market, and policy support for diversified systems.
- Society-wide waste management systems that fail to return organic residues to the land.
- Unrealized potential to expand urban agriculture, agroforestry, and permaculture practices, which are known for their high per-acre C sequestration potential.

Conclusion

A national and global investment in further research into these topics is urgently needed to enable all producers—organic, transitioning, and non-organic—to make effective contributions to climate mitigation and to enhance the resilience of their farming and ranching systems to impacts of climate change. Based on research outcomes to date, producers and society as a whole can anticipate a substantial return on investment in this field of research.

References

Aguilera, E., L. Lassaletta, A. Gattinger, and B.S. Gimeno. 2013. *Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: a meta-analysis.* AGRIC. ECOSYST. ENVIRON. 168, 25–36.

Alhameid, A., M. Ibrahim, S. Kumar, P. Sexton, and T.E. Schumacher. 2017. *Soil Organic Carbon Changes Impacted by Crop Rotational Diversity under No-Till Farming in South Dakota, U.S.A.* SOIL SCI. SOC. AM. J. 81(4): 868–877.

Andrews, S. 2006. *Crop residue removal for biomass energy production: effects on soils and recommendations.* White Paper published for NRCS soil Quality National Technology Development Team, updated February 22, 2006. 15 pp.

Baas, D.G., G.P. Robertson, S.R. Miller, N. and Millar, N. 2015. *Effects of Cover Crops on Nitrous Oxide Emissions, Nitrogen Availability, and Carbon Accumulation in Organic* ***versus*** *Conventionally Managed Systems.* Final report for ORG project 2011–04952. CRIS Abstracts.*

Balaine, N., T.J. Clough, M.H. Beare, S.M. Thomas, and E.D. Meenken. 2016. *Soil Gas Diffusivity Controls* N_2O and N2 Emissions and their Ratio. SOIL SCI. SOC. AM. J. 80(3): 529–540.

Ball, B.C., C.A. Watson, and I. Crichton. 2007. *Nitrous oxide emissions, cereal growth, N recovery and soil nitrogen status after ploughing organically managed grass/clover swards.* SOIL USE. MANAG. 23, 145–155.

Barbercheck, M.E., D.A. Mortensen, H. Karsten, E.S. Sanchez, S.W. Duiker, J.A. Hyde, and N.E. Kiernan. 2008. *Organic Weed Management: Balancing Pest Management and Soil Quality in a Transitional System.* Final report on ORG project 2003–04619. CRIS Abstracts.*

Basche, A.D., F.E. Miguez, T.C. Kaspar, and M.J. Castellano. 2014. *Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis.* J. Soil Water Conserv. 69(6): 471–482.

Bhowmik, A. A-M. Fortuna, L.J. Cihacek, A. Bary, P.M. Carr, and C.G. Cogger. 2017. *Potential carbon sequestration and nitrogen cycling in long-term organic management systems.* Renewable Agriculture and Food Systems, 32(6): 498–510.

Bhowmik, A., A-M. Fortuna, L.J. Cihacek, and P.M. Carr. 2015. *Use of Laboratory Incubation Techniques to Estimate GHG Footprints from Clean and No-Tillage Organic Agroecosystems.* ASA–CSSA–SSSA Meetings Nov. 15–18, 2015 Minneapolis, oral presentation. *https://scisoc.confex.com/crops/2015am/webprogram/start.html*.

Blanco-Canqui, H. 2017. *Biochar and Soil Physical Properties.* Soil Sci. Soc. Am. J. 81(4): 687–711.

Blanco-Canqui, H., and C.A. Francis. 2016. *Building resilient soils through agroecosystem redesign under fluctuating climatic regimes.* J. Soil & Water Conserv. 71(6): 127A–133A.

Blanco-Canqui, H., A.L. Stalker, R. Rasby, T.M. Shaver, M.E. Drewnoski, S. van Donk, and L. Kibet. 2016a. *Does Cattle Grazing and Baling of Corn Residue Increase Water Erosion?* Soil Sci. Soc. Am. J. 80(1): 168–177.

Blanco-Canqui, H., J. Tatarko, A.L. Stalker, T.M. Shaver, and S.J. van Donk. 2016b. *Impacts of Corn Residue Grazing and Baling on Wind Erosion Potential in a Semiarid Environment.* Soil Sci. Soc. Am. J. 80(4): 1027–1037.

Brady, N.C., and R.R. Weil. 2008. *The Nature and Properties of Soils,* 14th Edition. Pearson Education, Inc., Upper Saddle, NJ. 992 pp.

Brown, S., C. Kruger, and S. Subler. 2008. *Greenhouse gas balance for composting operations.* Journal of Environmental Quality 37: 1396–1410.

Burger, M., L.E. Jackson, E.J. Lundquist, D.T. Louie, R.L. Miller, D.E. Rolston, and K. Scow. 2005. *Microbial responses and nitrous oxide emissions during wetting and drying of organically and conventionally managed soil under tomatoes.* Biol. Fertil. Soils 42: 109–18.

Cai, Z., S. Gao, A. Hendratna, Y. Duan, M. Xu, and B.D. Hanson. 2016. *Key Factors, Soil Nitrogen Processes, and Nitrite Accumulation Affecting Nitrous Oxide Emissions.* Soil Science Society of America Journal 80(6): 1560–1571.

Carpenter-Boggs, L., D. Granatstein, and D. Huggins. 2016. *Greenhouse Gases and Agriculture: Where does Organic Farming Fit* (Webinar). *http://articles.extension.org/pages/30835/greenhouse-gases-andagriculture:-where-does-organic-farming-fit-webinar*.

Cavigelli, M. 2010. *Impact of Organic Grain Farming Methods on Climate Change* (Webinar) *http://articles.extension.org/pages/30850/impact-of-organic-grain-farming-methods-on-climate-change-webinar*.

Cavigelli, M.A., J.R. Teasdale, and J.T. Spargo. 2013. *Increasing Crop Rotation Diversity Improves Agronomic, Economic, and Environmental Performance of Organic Grain Cropping Systems at the USDA–ARS Beltsville Farming Systems Project.* Crop Management 12(1) Symposium Proceedings: USDA Organic Farming Systems Research Conference. *https://dl.sciencesocieties.org/publications/cm/tocs/12/1*.

Chambers, A., R. Lal, and K. Paustian. 2016. *Soil carbon sequestration potential of U.S. croplands and grasslands: implementing the 4 per Thousand Initiative.* J. Soil & Water Conserv. 71(3): 68A–74A

Charles, A., P. Rochette, J.K. Whalen, D.A. Angers, M.H. Chantigny, and N. Bertrand. 2017. *Global nitrous oxide emission factors from agricultural soils after addition of organic amendments: A meta-analysis.* Agriculture, Ecosystems and Environment 236: 88–98

Cogger, C., A. Fortuna, and D. Collins. 2014. *Why the Concern about Nitrous Oxide Emissions?* Webinar 1 at: *http://articles.extension.org/pages/70280/two-part-webinar-series-on-greenhouse-gas-emissions-and-soil-quality-in-long-term-integrated-and-tra*.

Cogger, C.G.M. Ostrom, K. Painter, A. Kennedy, A. Fortuna, R. Alldredge, A.; Bary, T. Miller, D. Collins, J. Goldberger, A. Antonelli, and B. Cha. 2013. *Designing Production Strategies for Stewardship and Profits On Fresh Market Organic Farms.* Final report for OREI project 2008–01247. CRIS Abstracts.*

Collins, D.P. and A. Bary. 2017. *Optimizing nitrogen management on organic and biologically intensive farms.* Proceedings of the Special Symposium on Organic Agriculture Soil Health Research at the Tri-Societies Annual Meeting, Tampa, FL, October 22–25, 2017. *http://articles.extension.org/pages/74555/livebroadcast:-organic-soil-health-research-special-session-at-the-tri-societies-conference*.

Coulter, J.A., T.A. Delbridge, R.P. King, D.L. Allan, and C.C. Sheaffer. 2012. *Productivity, Economics, and Soil Quality in the Minnesota Variable-Input Cropping Systems Trial.* Crop Management—Symposium Proceedings: USDA Organic Farming Systems Research Conference. Crop Management 12(1): *https://dl.sciencesocieties.org/publications/cm/tocs/12/1*.

Daigh, A.L. and J. Dejong-Hughes. 2017. *Fluffy soil syndrome: when tilled soil does not settle.* J. Soil & Water Conserv. 72(1); 10A–14A.

Delate, K. 2013. *Developing Carbon-positive Organic Systems through Reduced Tillage and Cover Crop Intensive Crop Rotation Schemes.* Final report for ORG project 2008–01284. CRIS Abstracts.*

Delate, K., C. Cambardella, and C. Chase. 2015a. *Effects of cover crops, soil amendments, and reduced tillage on carbon sequestration and soil health in a long-term vegetable system.* Final report for ORG project 2010–03956. CRIS Abstracts*

Delate, K., C. Cambardella, C. Chase, and R. Turnbull. 2015b. *A review of long-term organic comparison trials in the U.S.* Sustainable Agricultural Research 4(3): 5–14.

Delgado, J.A., P.M. Groffman, M.A. Nearing, T. Goddard, D. Reicosky, R. Lal, N.R. Kitchen, C.W. Rice, D. Towery, and P. Salon. 2011. *Conservation practices to mitigate and adapt to climate change.* J. Soil Water Conserv. 66: 118A–129A.

DeLonge, M.S., R. Ryals, and W.L. Silver. 2013. *A lifecycle model to evaluate carbon sequestration potential and greenhouse gas dynamics of managed grasslands.* Ecosystems 16: 962–979.

Dimitri, C., L. Kemp, J. Sooby, and E. Sullivan. 2012. *Organic Farming for Health and Prosperity.* Organic Farming Research Foundation (*www.ofrf.org*), 76 pp.

Dou, F., M. Hons, J. Pl Wight, and H.A. Torbert. 2016. *Improving soil quality, C sequestration, and mitigating greenhouse gas emissions in organic rice production.* Proposal and final report for ORG project 2012–02983. CRIS Abstracts.*

Douds, D. 2015. *On-farm Production and Utilization of AM Fungus Inoculum. http://articles.extension.org/pages/18627/on-farm-production-and-utilization-of-am-fungus-inoculum*.

Duncan, J. 2017. *Cover crop options for hot and humid areas.* ATTRA Bulletin, National Center for Appropriate Technology, *www.attra.ncat.org*, 20 pp.

Eagle, A.J., L.P. Oander, K.L. Locklier, J.B. Heffernan, and E.S. Bernhardt. 2017. *Fertilizer Management and Environmental Factors Drive N_2O and NO_3 Losses in Corn: A Meta-Analysis.* Soil Sci. Soc. Am. J. 81(5): 1191–1202.

Environmental Protection Agency (EPA). 2018. *Sources of Greenhouse Gas Emissions. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions*.

Fauci, M.F., and R.P. Dick. 1994. *Soil Microbial Dynamics: Short- and Long-Term Effects of Inorganic and Organic Nitrogen.* Soil Sci. Soc. Am. J. 58(3): 801–806.

Feliciano, D., A. Ledo, J. Hillier, and D.R. Nayak. 2018. *Which agroforestry options give the greatest soil and above ground carbon benefits in different world regions?* Agriculture, Ecosystems, and Environment 254: 117–129.

Finney, D.M., J.S. Buyer, and J.P. Kaye. 2017. *Living cover crops have immediate impacts on soil microbial community structure and function.* J. Soil. & Water Conserv. 72(4): 361–373.

Fortuna, A., D. Collins, and C. Cogger. 2014. *Management to Reduce N_2*O Emissions in Organic Vegetable Production Systems. Webinars at: *http://articles.extension.org/pages/70280/two-part-webinar-series-on-greenhouse-gas-emissions-and-soil-quality-in-long-term-integrated-and-tra*.

Franzluebbers, A.J., and J.A. Stuedemann. 2015. *Does grazing of cover crops impact biologically active soil carbon and nitrogen fractions under inversion or no tillage management?* J. Soil & Water Conserv. 70(6): 365–373.

Galik, C.S., B.C. Murray, and M.C. Parish. 2017. *Near-Term Pathways for Achieving Forest and Agricultural Greenhouse Gas Mitigation in the U.S. Climate 2017,* 5, 69; *doi:10.3390/cli5030069 www.mdpi.com/journal/climate*.

Gattinger, A., A. Muller, M. Haeni, C. Skinner, A. Fliessbach, N. Buchmann, P. Mader, M. Stolze, P. Smith, N.E. Scialabba, and U. Niggli. 2012. *Enhanced top soil carbon stocks under organic farming,* Proceedings of the National Academy of Sciences 109 (44) 18826–18231.

Ghabbour, E.A., G. Davies, T. Misiewicz, R.A. Alami, E.M. Askounis, N.P. Cuozzo, A.J. Filice, J.M. Haskell, A.K. Moy, A.C. Roach, and J. Shade. 2017. *National Comparison of the Total and Sequestered Organic Matter Contents of Conventional and Organic Farm Soils.* Advances in Agronomy 146: 1–35.

Gottshall, C.B., M. Cooper, and Ss M. Emery. 2017. *Activity, diversity and function of arbuscular mycorrhizae vary with changes in agricultural management intensity.* Agriculture, Ecosystems and Environment 245: 142–149.

Grandy, S., and C. Kallenbach. 2015. *Microbes drive soil organic matter accumulation in organic cropping systems.* Recording from the Organic Agriculture Research Symposium LaCrosse, WI. February 25–26, 2015. *http://eorganic.info/node/12972*.

Grandy, A.S., G.P. Robertson, and K.D. Thelen. 2006. *Do Productivity and Environmental Tradeoffs Justify Periodically Cultivating No-till Cropping Systems?* Agron. J. 98(6): 1377–1383.

Gruver, J., R.R. Weil, C. White, and Y. Lawley. *2016 Radishes A New Cover Crop for Organic Farming Systems. http://articles.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farming-systems*.

Halvorson, A.D., B.J. Wienhold, and A.L. Black. 2002. *Tillage, nitrogen, and cropping system effects on soil carbon sequestration.* Soil Sci. Soc. Am. J. 66(3): 906–912.

Hamel, C. 2004. *Impact of arbuscular mycorrhizal fungi on N and P cycling in the root zone.* Can. J. Soil Sci. 84(4): 383–395.

Han, Z., M.T. Walter, and L.E. Drinkwater. 2017. *Impact of cover cropping and landscape positions on nitrous oxide emissions in northeastern U.S. agroecosystems.* Agriculture, Ecosystems and Environment 245: 124–134.

Harden, J.W., G. Hugelius, A. Ahlström, J.C. Blankinship, B. Bond-Lamberty, C.R. Lawrence, J. Loisel, A. Malhotra, R.B. Jackson, S. Ogle, C. Phillips, R. Ryals, K. Todd-Brown, R. Vargas, S.E. Vergara, M.F. Cotrufo, M. Keiluweit, K.A. Heckman, S.E. Crow, W.L. Silver, M. DeLonge, and L.E. Nave. 2018. *Networking our science to characterize the state, vulnerabilities, and management opportunities of soil organic matter.* Global Change Biology (2018) 24: e705–e718.

Hooks, C.R., K.H. Wang, G. Brust, and S. Mathew. 2015. *Using Winter Cover Crops to Enhance the Organic Vegetable Industry in the Mid-Atlantic Region.* Final report for OREI project 2010–01954. CRIS Abstracts.*

Hu, S., C. Reberg-Horton, M. Schroeder-Moreno, Y. Cardoza, J. Grossman, W. Robarge, and W. Eveman. 2016. *Assessing the Greenhouse Gas Mitigation Potential of Organic Systems in the Southeast.* Progress report for ORG project 2012–02978. CRIS Abstracts.*

Hu, T., P. Sorensen, E.M. Wahlstrom, N. Chirinda, B. Sharif, X. Li, and J.E. Olesen. 2018. *Root biomass in cereals, catch crops and weeds can be reliably estimated without considering aboveground biomass.* Agriculture, Ecosystems, and Environment 251: 141–148.

Hurisso, T.T., S.W. Culman, W.R. Horwath, J. Wade, D. Cass, J.W. Beniston, T.M. Bowles, A.S. Grandy, A.J. Franzluebbers, M.E. Schipanski, S.T. Lucas, and C.M. Ugarte. 2016. *Comparison of Permanganate-Oxidizable Carbon and Mineralizable Carbon for Assessment of Organic Matter Stabilization and Mineralization.* Soil Sci. Soc. Am. J. 80(5): 1352–1364.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Mitigation of Climate Change, Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change *https://www.ipcc.ch/report/ar5/wg3/. Chapter 11 Agriculture, Forestry, and Other Land Use (AFOLU),* and *Annex II Metrics and Methodology.*

Intergovernmental Technical Panel on Soils (ITPS). 2015. *Status of the World's Soil Resources: Technical Summary.* United Nations Food and Agriculture Organization.

Jackson, L. 2013. *Researcher and Farmer Innovation to Increase Nutrient Cycling on Organic Farms.* Proposal and final report for OREI project 2009–01415. CRIS Abstracts.*

Jackson, L. and T. Bowles. 2013. *Researcher and Farmer Innovation to Increase Nitrogen Cycling on Organic Farms* (Webinar). *http://articles.extension.org/pages/67391/researcher-and-farmer-innovation-to-increase-nitrogen-cycling-on-organic-farms-webinar*.

Jackson, L., V.R. Haden, A.D. Hollander, H. Lee, M. Lubell, V.K. Mehta, T. O'Geen, M. Niles, J. Perlman, D. Purkey, W. Salas, D. Sumner, M. Tomuta, M. Demsey, and S.M. Wheeler. 2012. *Adaptation Strategies for Agricultural Sustainability in Yolo County, California: a White Paper from the California Energy Commission's California Climate Change Center.* University of California, Davis. 205 pp. *http://www.energy.ca.gov/2012publications/CEC-500-2012-032/CEC-500-2012-032.pdf.*

Jones, C. 2010. *Soil carbon: can it save agriculture's bacon? http://www.amazingcarbon.com/PDF/JONES-SoilCarbon&AgricultureREVISED(18May10).pdf.*

Kane, D. 2015. *Carbon sequestration potential on agricultural lands: a review of current science and available practices.* Breakthrough Strategies and Solutions and National Sustainable Agriculture Coalition. *http://sustainableagriculture.net.publications.* 35 pp.

Kell, D.B. 2011. *Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration.* Ann. Bot. 108(3): 407–418.

Khan, S.A., R.L. Mulvaney, T.R. Ellsworth, and C.W. Boast. 2007. *The myth of nitrogen fertilization for soil carbon sequestration.* J. Environ. Qual. 36: 1821–1832.

King, A.E., and K.S. Hofmockel. 2017. *Diversified cropping systems support greater microbial cycling and retention of carbon and nitrogen.* Agriculture, Ecosystems and Environment 240: 66–76.

Kirschbaum, M.U.F. 1995. *The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage.* Soil Biology and Biochemistry. 27(6): 753–760.

Kittredge, J. 2014–15. *Grazing success through observation and planning at Bishopp Family Farm.* The Natural Farmer, winter 2014–15, pp. B23–B26.

Kittredge, J. 2015 *Introduction to biochar in agriculture.* The Natural Farmer, fall 2015, pp. B1–B3.

Kittredge, J. 2016–17. *The truth about ruminants and methane.* The Natural Farmer, winter 2016–17, p. 18.

Lal, R. 2003. *Soil erosion and the global carbon budget.* Environment International 29: 437–450.

Lal, R. 2015. *Cover cropping and the "4 per thousand" proposal.* J. Soil & Water Conserv. 70(6): 141A.

Lal, R. 2016. *Beyond COP21: Potential challenges of the "4 per thousand" initiative.* J. Soil & Water Conserv. 71(1): 20A–25A.

Larsen E.J. Grossman, J. Edgell, G. Hoyt G.D. Osmond D, and S. Hu. 2014. *Soil biological properties, soil losses and corn yield in long-term organic and conventional farming systems.* Soil Tillage Res. 139: 37–45.

Lee, K.S., Y.C. Choe, and S.H. Park. 2015. *Measuring the environmental effects of organic farming: a meta-analysis of structural variables in empirical research.* J. Environ. Manag. 162, 263–274.

Lehman, R.M., S.L. Osborne, and S.E. Duke. 2017. *Diversified No-Till Crop Rotation Reduces Nitrous Oxide Emissions, Increases Soybean Yields, and Promotes Soil Carbon Accrual.* Soil Sci. Soc. Am. J. 81(1): 76–83.

Lehmann, J., and M. Kleber. 2015. *The Contentions Nature of Soil Organic Matter.* Nature 528: 60–68.

Lengnick, L. 2016. *New Times, New Tools: Cultivating Climate Resilience on Your Organic Farm. http://articles.extension.org/pages/73466/new-times-new-tools:-cultivating-climate-resilience-on-your-organic-farm.*

Li, C., Salas, W. and Muramoto, J. 2009. *Process Based Models for Optimizing N Management in California Cropping Systems: Application of DNDC Model for nutrient management for organic broccoli production.* Conference proceedings 2009 California Soil and Plant Conference, 92–98. Feb. 2009. http://ucanr.edu/sites/calasa/files/319.pdf.

Linn, D., and J. Doran. 1984. *Effect of Water-Filled Pore-Space on Carbon-Dioxide and Nitrous-Oxide Production in Tilled and Non-tilled Soils.* Soil Sci. Soc. Am. J. 48(6): 1267–1272.

Lorenz, K., and R. Lal. 2016. *Environmental Impact of Organic Agriculture.* Advances in Agronomy 139: 99–152.

Lori, M., S. Symnaczik, P. MaEder, G. De Deyn, A. Gattinger. 2017. *Organic farming enhances soil microbial abundance and activity—A meta-analysis and meta-regression.* PLoS One *https://doi.org/10.1371/journal.pone.0180442* July 12, 2017, 25 pp.

Lugato, E., A. Leip, and A. Jones. 2018. *Mitigation potential of soil carbon management overestimated by neglecting* N_2O emissions. Nature Climate Change 8: 219–223. *www.nature.com/natureclimatechange.*

Luo, J.J. Wyatt, T.J. van der Weerden, S.M. Thomas, C.A.M. de Klein, Y. Li., M. Rollo, S. Lindsey, S.F. Ledgard, J. Li, W. Ding, S. Qin, N. Zhang, N. Bolan, M.B. Kirkham, Z. Bai, L. Ma, X. Zhang, H. Wang, H. Liu, G. Rys, *et al.,* 2017. *Potential Hotspot Areas of Nitrous Oxide Emissions From Grazed Pastoral Dairy Farm Systems.* Advances in Agronomy 145: 205–268.

Maas, E.D. v. L., R. Lal, K. Coleman, A. Montenegro, and W.A. Dick. 2017. *Modeling soil organic carbon in corn (**Zea mays** L.)-based systems in Ohio under climate change.* J. Soil & Water Conserv. 72(3): 191–204.

Machmuller, M.B., M.G. Kramer, T.K. Cyle, N. Hill, D. Hancock, and A. Thompson. 2015. *Emerging land use practices rapidly increase soil organic matter.* Nat. Commun. 6:6995. *doi:10.1038/ncomms7995.*

Manale, A., S. Hyberg, N. Key, S. Mooney, T.L. Napier, and M. Ribaudo. 2016. *Climate change and U.S. agriculture: opportunities for conservation to reduce and mitigate emissions and to support adaptation to rapid change.* J. Soil & Water Conserv. 71(1): 69–81.

Marshall, M.W., P. Williams, A. Mirzakhani Nafchi, J.M. Maja, J. Payero, J. Mueller, and A. Khalilian. 2016. *Influence of Tillage and Deep Rooted Cool Season Cover Crops on Soil Properties, Pests, and Yield Responses in Cotton.* Open Journal of Soil Science, 6, 149–158. *http://dx.doi.org/10.4236/ojss.2016.610015.*

McDaniel M.D., L.K., Tiemann, and S. Grandy. 2014. *Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis.* Ecol. Appl. 24(3): 560–70.

McGee, J.A., 2015. *Does certified organic farming reduce greenhouse gas emissions from agricultural production?* Agric. Hum. Values 32, 255–263.

McLauchlan K. 2006. *The nature and longevity of agricultural impacts on soil carbon and nutrients: A review.* Ecosystems 9(8): 1364–82.

Mia, S., F.A. Dijkstra, B. Singh. 2017. *Long-Term Aging of Biochar: A Molecular Understanding With Agricultural and Environmental Implications.* Advances in Agronomy 141: 1–51.

Millar, N., G.P. Robertson, P.R. Grace, R.J. Gehl, and J.P. Hoben. 2010. *Nitrogen fertilizer management for nitrous oxide* (N_2O) mitigation in intensive corn (Maize) production: an emissions reduction protocol for U.S. Midwest agriculture. Mitig. Adapt. Strateg. Glob. Change 15(2): 185–204.

Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, D.W. Wolfe, and G.S. Abawi. 2016. *Comprehensive Assessment of Soil Health: the Cornell Framework.* Edition 3.1. Cornell University, Geneva, NY. 123 pp. Available at *http://soilhealth.cals.cornell.edu/training-manual/.*

North, K. 2015. *Biochar: a Critical View Through the Ecosystemic Lens.* The Natural Farmer. Fall 2015. *Special Supplement on Biochar in Agriculture,* pp. B–23–B27. *http://thenaturalfarmer.org/issue/fall-2015/.*

Ohlson, K. 2014. *The Soil will Save Us: how scientists, farmers, and foodies are healing the soil to save the planet.* Rodale Press, *http://rodalebooks.com*, 242 pp.

Olson K.R., M. Al-Kasai, R. Lal, and L. Cihacek. 2016. *Impact of soil erosion on soil organic carbon stocks.* J. Soil & Water Conserv. 71(3): 61A–67A.

Olson, K.R., M. Al-Kaisi, R. Lal, and L.W. Morton. 2017. *Soil ecosystem services and intensified cropping systems.* J. Soil & Water Conserv. 72(3): 64A–69A.

Oo, A.Z., S. Sudo, K. Inubushi, M. Mano, A. Yamamoto, K. Ono, T. Osawa, S. Hayashida, P.K. Patra, Y. Terao, P. Elayakumar, K. Vanitha, C. Umamageswari, P. Jothimani, and V. Ravi. 2018. *Methane and nitrous oxide emissions from conventional and modified rice cultivation systems in South India.* Agriculture, Ecosystems, and Environment 252: 148–158.

Osmond, D.L., J.M. Grossman, G. Jennings, G.D. Hoyt, M. Reyes, and D. Line. 2014. *Water Quality Evaluation of Long Term Organic and Conventional Vegetable Production under Conservation and Conventional Tillage.* Final report on ORG project 2009–05488. CRIS Abstracts.*

Panicker, G.K. 2017. October 9 response to September 28 blog post by National Sustainable Agriculture Coalition, *Conservation Groups Deliver Farm Bill Recommendations,* available at *http://sustainableagriculture.net/blog/conservation-consensus/.*

Pardon, P., B. Reubens, D. Reheul, J. Mertens, P. De Frenne, T. Coussement, P. Janssens, and K. Verheyen. 2017. *Trees increase soil organic carbon and nutrient availability in temperate agroforestry systems.* Agriculture, Ecosystems and Environment 246: 98–111.

Parkin, T.B., and R.T. Venterea. 2010. USDA–ARS GRACEnet Project Protocols. *Chapter 3. Chamber-Based Trace Gas Flux Measurements.* 39 pp. *https://www.ars.usda.gov/ARSUserFiles/np212/Chapter%203.%20GRACEnet%20Trace%20Gas%20Sampling%20Protocols.pdf.*

Parkin, T.B., T.C. Kaspar, D.B. Jaynes and T.B. Moorman. 2016. *Rye Cover Crop Effects on Direct and Indirect Nitrous Oxide Emissions.* Soil Sci. Soc. Am. J. 80(6): 1551–1559.

Petit, C. 2012. *Soil's hidden secrets.* Science News 181(2): 16. *https://www.sciencenews.org/.*

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2014. *Diversification practices reduce organic to conventional yield gap.* Proc. R. Soc. B 282, 20141396.

Powlson, D.S., C.M. Stirling, C. Thierfelder, R.P. White and M.L. Jat. 2016. *Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? 2016.* Agriculture, Ecosystems and Environment 220: 164–174.

Powlson, D.S., A.P. Whitmore, and K.W.T. Goulding. 2011. *Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false.* Eur. J. Soil Sci. 62(1): 42–55.

Rasse, D.P., C. Rumpel, and M.-F. Dignac. 2005. *Is soil carbon mostly root carbon? Mechanisms for a specific stabilization.* Plant and Soil 269: 341–356.

Reeve, J., and E. Creech. 2015. *Compost Carryover Effects on Soil Quality and Productivity in Organic Dryland Wheat. http://articles.extension.org/pages/73247/compost-carryover-effects-on-soil-quality-and-productivity-in-organic-dryland-wheat.*

Reinbott, T. 2015. *Identification of factors affecting carbon sequestration and nitrous oxide emissions in three organic cropping systems.* Final report on ORG project 2011–04958. CRIS Abstracts.*

Richard, T. and G. Camargo. 2011. *Greenhouse Gas Emissions Associated with Dairy Farming Systems. http://articles.extension.org/pages/32626/greenhouse-gas-emissions-associated-with-dairy-farming-systemswebinar.*

Rillig, M.C. 2004. *Arbuscular mycorrhizae, glomalin, and soil aggregation.* Can. J. Soil Sci. 84(4): 355–363.

Rodale Institute. 2014. *Regenerative organic agriculture and climate change: a down-to-earth solution to global warming.* 16 pp. *https://rodaleinstitute.org/assets/RegenOrgAgricultureAndClimateChange_20140418.pdf.*

Rodale Institute, 2015. *Farming Systems Trial Brochure,* 2 pp. *http://rodaleinstitute.org/assets/FST-Brochure-2015.pdf.*

Roper, W.R., D.L. Osmond, J.L. Heitman, M.G. Wagger, and S.C. Reberg-Horton. 2017. *Soil Health Indicators Do Not Differentiate among Agronomic Management Systems in North Carolina Soils.* Soil Sci. Soc, Am. J. 81(4): 828–843.

Rose, M.T., T.R. Cavagnaro, C., Scanlan, T.J. Rose, T. Vancov, S. Kimber, I.R. Kennedy, R.S. Kookana, and L. Van Zweiten. 2016. *Impact of Herbicides on Soil Biology and Function.* Advances in Agronomy Vol. 136: 133–220.

Rosolem, C.A., K. Ritz, H. Cantarella, M.V. Galdos, M.J. Hawkesford, W.R. Whalley, and S.J. Mooney. 2017. *Enhanced plant rooting and crop system management for improved N use efficiency.* Advances in Agronomy 146: 205–239.

Rowntree, J.E., R. Ryals, M.S. DeLonge, W.R. Teague, M.B. Chiavegato, P. Byck, and T. Wang. 2016. *Potential mitigation of Midwest grass-finished beef production emissions with soil carbon sequestration in the United States of America.* Future Food J. Food Agric. Soc. 4: 31–38.

Ryals, R., and W.L. Silver. 2013. *Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands.* Ecol. Appl. 23(1): 46–59.

Sadeghpour, A., Q.M. Ketterings, G.S. Godwin, K.J. Czymmek, and F. Vermeylen. 2017. *Agro-Environmental Consequences of Shifting from Nitrogen- to Phosphorus-Based Manure Management of Corn.* Soil Sci. Soc. Am. J. 81(5): 1127–1138.

Schmidt, J.E., C. Peterson, D. Wang, M. Scow, A.C.M. Gaudin. 2018. *Agroecosystem tradeoffs associated with conversion to subsurface drip irrigation in organic systems.* Agricultural Water Management 202: 1–8.

Schonbeck, M., D. Jerkins, and J. Ory. 2016. *Taking stock: analyzing and reporting organic research investments, 2002–2014.* Organic Farming Research Foundation (*www.ofrf.org*), 222 pp.

Schonbeck, M., D. Jerkins, and J. Ory. 2017. *Soil Health and Organic Farming: Practical Conservation Tillage.* Organic Farming Research Foundation (*www.ofrf.org*), 30 pp.

Scialabba, N.E. 2013. *Organic Agriculture's Contribution to Sustainability.* SYMPOSIUM PROCEEDINGS: USDA ORGANIC FARMING SYSTEMS RESEARCH CONFERENCE. *https://dl.sciencesocieties.org/publications/cm/tocs/12/1.*

Six, J., R. Conant, E. Paul, and K. Paustian. 2002. *Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils.* PLANT SOIL 241(2): 155–176.

Skinner, C., A. Gattinger, A. Muller, P. Mader, A. Fliessbach, M. Stolze, R. Ruser, and U. Niggli. 2014. *Greenhouse gas fluxes from agricultural soils under organic and non-organic management—a global meta-analysis.* SCI. TOTAL ENVIRON. 468–469: 553–563.

Stanley, P.L., J.E. Rowntree, D.K. Beede, M.S. DeLonge, and M.W. Hamm. 2018. *Impacts of Soil Carbon Sequestration on Life Cycle Greenhouse Gas Emissions in Midwestern USA Beef Finishing Systems.* AGRICULTURAL SYSTEMS 162: 249–58. *https://doi.org/10.1016/j.agsy.2018.02.003.*

Stephensen, G., L. Gwin, C. Schreiner, and S. Brown. 2017. *Breaking new ground: farmer perspectives on organic transition.* Oregon Tilth and Oregon State University's Center for Small Farms & Community Food Systems. 53 pp. *https://tilth.org/resources/breakingground/.*

Sun H., P. Koal, D. Liu, G. Gerl, R. Schroll, A. Gattinger, R.G. Joergensen, and J.C. Munch. 2016. *Soil microbial community and microbial residues respond positively to minimum tillage under organic farming in Southern Germany.* APPL. SOIL ECOL. 108: 16–24.

Syswerda, S.P., A.T. Corbin, D.L. Mokma, A.N. Kravchenko, and G.P. Robertson. 2011. *Agricultural Management and Soil Carbon Storage in Surface vs. Deep Layers.* SOIL SCI. SOC. AM. J. 75(1): 92–101.

Tariq, A., Q.D. Vu, L.S. Jensen, S. de Tourdonnet, B.O. Sander, R. Wassmann, T. Van Mai, and A. de Neergaard. 2017. *Mitigating CH_4* and N_2O emissions from intensive rice production systems in northern Vietnam: Efficiency of drainage patterns in combination with rice residue incorporation. AGRICULTURE, ECOSYSTEMS, AND ENVIRONMENT 249: 101–111.

Teague, R. 2016–17. *Regeneration of soil by multi-paddock grazing.* Transcript of Sept. 7, 2016 presentation at Harvard by Jack Kittredge. *The Natural Farmer,* winter 2016–17: B26–B30.

Teague, W.R., 2018. *Forages and pastures symposium: cover crops in livestock production: whole-system approach: Managing grazing to restore soil health and farm livelihoods.* JOURNAL OF ANIMAL SCIENCE 96, 1519–1530.

Teague, W. R., S. Apfelbaum, R. Lal, U.P. Kreuter, J. Rowntree, C.A. Davies, R. Conser, M. Rasmussen, J. Hatfield, T. Wang, R Wang, and P. Byck. 2016. *The role of ruminants in reducing agriculture's carbon footprint in North America.* J. SOIL & WATER CONSERV. 71(2): 156–164.

Thakur, A.K., N.T. Uphoff, and W.A. Stoop. 2016. *Scientific Underpinnings of the System of Rice Intensification (SRI): What Is Known So Far?* ADVANCES IN AGRONOMY 135: 147–179.

Thies, J.E. 2007. *Nitrous oxide losses during soil freeze-thaw events during winter. http://impact.cals.cornell.edu/project/nitrous-oxide-losses-during-soil-freeze-thaw-events-during-winter.*

Thomas, B.W., X. Hao, F.J. Larney, C. Gover, M.H. Chantigny, and A. Charles. 2017. *Non-Legume Cover Crops Can Increase Non-Growing Season Nitrous Oxide Emissions.* SOIL SCI. AM. J. 81(1): 189–199.

Tiemann, L.K., A.S. Grandy, E.E. Atkinson, E. Marin-Spiotta, and M.D. McDaniel. 2015. *Crop rotational diversity enhances belowground communities and functions in an agroecosystem.* ECOL. LETT. 18(8): 761–771.

Toonsiri, P., S.J. Del Grosso, A. Sukor, and J.G. Davis. 2016. *Greenhouse Gas Emissions from Solid and Liquid Organic Fertilizers Applied to Lettuce.* J. ENVIRONMENTAL QUALITY Vol. 45 No. 6, p. 1812–1821.

Topp, E. and E. Pattey. 1997. *Soils as sources and sinks for atmospheric methane.* CAN. J. SOIL SCI. 167–178.

Tubiello, F.N., M. Salvatore, S. Rossi, A. Ferrara, N. Fitton, and P. Smith. 2013. *The FAOSTAT database of greenhouse gas emissions from agriculture.* ENVIRONMENTAL RESEARCH LETTERS 8: 015009 (10 pp.). *doi:10.1088/1748-9326/8/1/015009.*

USDA. 2016. *USDA Building Blocks for Climate-Smart Agriculture and Forestry: Implementation Plan and Progress Report.* 60 pp. *https://www.usda.gov/sites/default/files/documents/building-blocks-implementation-plan-progress-report.pdf.*

USDA National Organic Program Final Rule, *https://www.ams.usda.gov/rules-regulations/organic.*

USDA Natural Resources Conservation Service. Soil health. *https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/*, and Conservation Stewardship Program, *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/.*

USDA Natural Resources Conservation Service. 2011. *Soil quality indicators: Particulate Organic Matter.* April, 2011. 2 pp. Accessed via Soil health assessment, *https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/assessment/.*

USDA Natural Resources Conservation Service, 2014. *National Planning Procedures Handbook (NPPH),* Edition 1. *https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=36483.wba.*

Van Geel, M., E. Verbruggen, M. De Beenhouwer, G. van Rennes, B. Lievens, and O. Honnay. 2017. *High soil phosphorus levels overrule the potential benefits of organic farming on arbuscular mycorrhizal diversity in northern vineyards.* AGRICULTURE, ECOSYSTEMS, AND ENVIRONMENT 248: 144–152.

Wander, M.M. 2015. *Nutrient budget basics for organic farming systems.* 6 pp. *http://articles.extension.org/pages/18794/nutrient-budget-basics-for-organic-farming-systems.*

Wander, M.M., S.J. Traina, B.R. Stinner, and S.E. Peters. 1994. *Organic and Conventional Management Effects on Biologically Active Soil Organic Matter Pools.* SOIL SCI. SOC. AM. J. 58: 1130–1139.

Wander, M.M., C. Ugarte, E. Zaborski, and E. Phillips. 2014. *Organic systems and climate change.* Proposal and final report for ORG project 2010–03954. CRIS Abstracts.*

Wang, T., W.R. Teague, S.C. Park, and S. Bevers. 2015. *GHG mitigation and profitability potential of different grazing systems in Southern great plain.* SUSTAINABILITY 7: 13500–13521.

West, T.O., and W.M. Post. 2002. *Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis.* SOIL SCI. SOC. AM. J. 66(6): 1930–1946.

Westphal, M., M. Tenuta, and M.H. Entz. 2018. *Nitrous oxide emissions with organic crop production depends on fall soil moisture.* AGRICULTURE, ECOSYSTEMS, AND THE ENVIRONMENT 254: 41–49.

Wild Farm Alliance. 2017. *Making Biodiversity a Priority: Updating Organic System Plans.* 10 pp. Available at *www.WildFarmAlliance.org.*

Williams, A., A.S. Davis, A. Jilling, A.S. Grandy, R.T. Koide, D.A. Mortensen, R.G. Smith, S.S. Snapp, K.A. Spokas, A.C. Yannarell, and N.R. Jordan. 2017. *Reconciling opposing soil processes in row-crop agroecosystems via soil functional zone management.* AG. ECO. ENV. 236: 99–107.

Wilson, G.W.T., C.W. Rice, M.C. Rillig, A. Springer, and D.C. Hartnett. 2009. *Soil aggregation and carbon sequestration are tightly correlated with the abundance of arbuscular mycorrhizal fungi: results from long-term field experiments.* ECOL. LETT. 12(5): 452–61.

Wilson, K. 2014. *How Biochar Works in Soil.* BIOCHAR JOURNAL, 2014. Excerpted by Jack Kittredge in THE NATURAL FARMER. Fall 2015. *Special Supplement on Biochar in Agriculture,* pp. B8–B12. *http://thenaturalfarmer.org/issue/fall-2015/.*

Wuest, S.B., and C.L. Reardon. 2016. *Surface and root inputs produce different carbon/phosphorus ratios in soil.* SOIL SCI. SOC. AM. J. 80: 463–471.

Zhang, Q., G. Liang, W. Zhou, J. Sun, X. Wang and P. He. 2016. *Fatty-Acid Profiles and Enzyme Activities in Soil Particle-Size Fractions under Long-Term Fertilization.* SOIL SCI. SOC. AM. J. 80(1): 97–111.

Zhong, L., S. Bowatte, P.C.D. Newton, C.J. Hoogendoorn, and D. Luo. 2018. *An increased ratio of fungi to bacteria indicates greater potential for N_2*O production in a grazed grassland exposed to elevated CO_2. AGRICULTURE, ECOSYSTEMS, AND THE ENVIRONMENT 254: 111–116.

Zuber S.M., and M.B. Villamil. 2016. *Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities.* SOIL BIOL BIOCHEM. 97: 176–187.

* For project proposal summaries, progress and final reports for USDA funded Organic Research and Extension Initiative (OREI) and Organic Transitions (ORG) projects, enter proposal number under "Grant No" and click "Search" on the CRIS Assisted Search Page at: *http://cris.nifa.usda.gov/cgi-bin/starfinder/0?path=crisassist.txt&id=anon&pass=&OK=OK.*

Note that many of the final reports on the CRIS database include lists of publications in referred journals that provide research findings in greater detail.

SUBMITTED STATEMENT BY ABBY YOUNGBLOOD, EXECUTIVE DIRECTOR, NATIONAL ORGANIC COALITION

Chair Plaskett, Ranking Member Dunn, and Members of the Subcommittee:

I am Abby Youngblood, Executive Director for the National Organic Coalition. The National Organic Coalition is a national alliance of organizations representing the full spectrum of stakeholders with an interest in organic agriculture, including farmers, ranchers, conservationists, consumers, retailers, certifying agents, and organic industry members. NOC seeks to advance organic agriculture and ensure a united voice for organic integrity, which means strong, enforceable, and continuously improved standards to maximize the multiple health, environmental, and economic benefits that organic agriculture provides.

Thank you for the opportunity to provide testimony on the research and extension needs to farmers to help mitigate risks, particularly those related to climate change.

First and foremost, it is critical that we be clear about the state of science with regard to climate change and the farming practices that can help solve our global climate change challenges. No doubt, the science in this area will continue to evolve. There is plenty that we do not fully understand about the relationship between agriculture and climate change. But there are also some very clear messages that can be gleaned from the existing research that can point us in the right direction.

In the organic agriculture sector, we are very excited and engaged in this topic because there is strong science showing that, in general, organic practices are climate-friendly practices. I welcome this opportunity to summarize what we have learned from the evolving science on this topic.

Important Role of Organic Agriculture in Addressing Climate Change

Organic agriculture has led innovations in farming for decades, particularly in the development of climate-friendly soil building techniques and farm inputs. Healthy soil is the cornerstone of organic agriculture and a critical solution for addressing climate challenges. Organic farming practices help mitigate climate change by keeping roots in the soil, preventing soil erosion, and sequestering soil carbon. Nutrient-rich, biodiverse soils foster the ability of crops to withstand and adapt to extreme weather-induced events such as droughts, floods, fire, and high winds. Accelerating the adoption of organic agricultural practices in the U.S. and abroad will go a long way toward solving the global climate crisis.

Organic Eliminates A Significant Source Of Nitrous Oxide Emissions

EPA estimates that U.S. agriculture contributes 8.6% to the country's anthropogenic greenhouse gas (GHG) emissions, releasing the equivalent of 574 million metric tons of carbon dioxide annually into the environment, mostly from fossil fuel production and use. Nitrous oxide emissions from soils comprise 50.4% of all domestic agricultural emissions.[1] The chemical is a long-lived GHG and ozone depleter, with 310 times the global warming potential of carbon dioxide.[2]

- Organic regulations (§ 205.105) prohibit the use of synthetic substances in crop production.
- Prohibiting synthetic fertilizers in organic eliminates a significant agricultural source of N_2O emissions. Since nitrogen is an essential plant nutrient, many organic farmers apply soil amendments such as manure and compost, and grow leguminous cover crops, to fix nitrogen in the soil.
- Efficient nitrogen use is key to reducing GHG emissions; aerated organic soils have low mobile nitrogen, which reduces N_2O emissions from agricultural fields.[3]
- The use of synthetic pesticides is largely prohibited in organic agriculture.[4] Synthetic pesticides disrupt nitrogen fixation and inhibit soil life. The absence of pesticides in the soil allows diverse organisms and beneficial insects to decompose plant residues and help sequester carbon.

Organic Practices Can Mitigate Climate Change

Healthy, biodiverse soils are integral to thriving organic farming systems and they also impact climate change. As biologically active soils break down crop residues, they release carbon dioxide and nutrients. Stabilized soil organic carbon that adheres to clay and silt particles or resists decomposition is sequestered and can remain in soils for decades or even millennia.

- Organic regulations (§ 205.203) require the implementation of soil fertility and crop nutrient management practices to maintain or improve soil such as crop rotations, cover cropping, and the application of plant and animal manures.

[1] Environmental Protection Agency (EPA). (2018) *Sources of Greenhouse Gas Emissions. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions*.

[2] Schonbeck, M., *et al.* (2018) Soil Health and Organic Farming, *Organic Practices for Climate Mitigation, Adaptation, and Carbon Sequestration, Organic Farming Research Foundation,* p. 2. *https://ofrf.org/soil-health-andorganic-farming-ecological-approach*.

[3] UNCTAD/WTO, FiBL. (2007) *Organic Farming and Climate Change,* Doc. No. MDS–08–152.E. Geneva, Switzerland. *http://orgprints.org/13414/3/niggli-etal-2008-itc-climate-change.pdf*.

[4] A small number of synthetic substances are allowed in organic, after review by the National Organic Standards Board (NOSB). The Organic Foods Production Act includes a list of review criteria that the Board must use in determining whether a synthetic substance may be used in organic, including "the effects of the substance on biological and chemical interactions in the agroecosystem, including the physiological effects of the substance on soil organisms (including the salt index and solubility of the soil)." (7 U.S.C. 6518(m)(5)).

- Research has shown that if the standard practices used by organic farmers to maintain and improve soils were implemented globally, it would increase soil organic carbon pools by an estimated 2 billion tons per year—the equivalent of 12% of the total annual GHG emissions, worldwide.[5]
- Cover crops, routinely planted by organic farmers after harvesting cash crops, rebuild soil nitrogen and improve carbon sequestration by adding soil organic matter. Planting deep-rooted cover crops like forage radish or cereal rye further aid in the long-term sequestration of carbon.
- Compost is an important organic farming soil amendment and, when used judiciously and in combination with cover crops, it accrues more soil organic carbon than when used alone.
- Adding compost to rangeland and intensively managing and rotating livestock can increase plant productivity and heighten carbon sequestration.
- Diverse crop rotations, using plants with deep, extensive root systems, play an important role in sequestering carbon. Research has shown that although most soil biological activity occurs near the earth's surface to take advantage of the sun, 53% of the global soil organic carbon is found at depths 12–39″ below the surface.[6]
- Prudent green and animal manure applications, crop rotations, intercropping, and cover cropping improve farm soils and help prevent soil erosion, which depletes the amount of carbon the soil is able to store.

The Role of No-Till Systems from a Climate Change Perspective

While no-till systems may show benefits in terms of building soil organic matter and reducing erosion, many of those systems are also chemical-intensive systems that can degrade the biological activity in the soil. Biologically active soils have been shown to be a key component to effective carbon sequestration in soil. Organic practices build soil structure as a way to reduce erosion, but also enhance soil biota.[7–14]

Organic Agriculture Increases Resilience to Climate Change

By design, organic agriculture builds resilience into the system of food production. Growing strong crops and livestock on healthy soils with bountiful biodiversity

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[5] *Ibid,* p. 42.

[6] Schonbeck, M., *et al.* (2018) p. 12.

[7] Wang, R., Zhang, H., Sun, L., Qi, G., Chen, S. and Zhao, X., 2017. *Microbial community composition is related to soil biological and chemical properties and bacterial wilt outbreak.* SCIENTIFIC REPORTS, 7(1), p. 343. It concludes: "In a conclusion, the higher abundance of beneficial microbes are positively related the higher soil quality, including better plant growth, lower disease incidence, and higher nutrient contents, soil enzyme activities and soil pH." Abd-Alla, M.H., Omar, S.A. and Karanxha, S., 2000. *The impact of pesticides on arbuscular mycorrhizal and nitrogen-fixing symbioses in legumes.* APPLIED SOIL ECOLOGY, 14(3), pp. 191–200. Shows that pesticide application reduces "beneficial" fungi, which negatively affected plant growth.

[8] Giovannetti, M., Turrini, A., Strani, P., Sbrana, C., Avio, L. and Pietrangeli, B., 2006. *Mycorrhizal fungi in ecotoxicological studies: soil impact of fungicides, insecticides and herbicides.* PREVENTION TODAY, 2(1–2), pp. 47–61. Found that spore germination and cell growth of mycorrhizae, *Glomus mosseae,* was adversely affected by pesticides used in agriculture, and in some cases, at much lower concentrations than are approved for use. The study indicates "the experimental tests demonstrated that spore germination and/or mycelial growth of *G. mosseae* are adversely affected by most of the substances tested and, in some cases, at much lower concentrations than those indicated for use." This justifies the use of AM fungi as a measure of soil health and links it with chemical use. Pesticide use is shown to have a negative effect on the AM fungus *Glomus mosseae.*

[9] The *Food and Agriculture Organization,* ***Annex 1 on Soil Organisms*** states: "Where the soil has received heavy treatments of pesticides, chemical fertilizers, soil fungicides or fumigants that kill these organisms, the beneficial soil organisms may die (impeding the performance of their activities), or the balance between the pathogens and beneficial organisms may be upset, allowing those called opportunists (*disease-causing organisms*) to become problems."

[10] Prashar, P. and Shah, S., 2016. *Impact of fertilizers and pesticides on soil microflora in agriculture.* In: SUSTAINABLE AGRICULTURE REVIEWS (pp. 331–361). Springer, Cham.

[11] Six, J., Frey, S.D., Thiet, R.K., & Batten, K.M. (2006). *Bacterial and Fungal Contributions to Carbon Sequestration in Agroecosystems.* SOIL SCIENCE SOCIETY OF AMERICA JOURNAL, 70(2), 555. *doi:10.2136/sssaj2004.0347*.

[12] Kallenbach, C.M., Grandy, A.S., Frey, S.D., & Diefendorf, A.F. (2015). *Microbial physiology and necromass regulate agricultural soil carbon accumulation.* SOIL BIOLOGY AND BIOCHEMISTRY, 91, 279–290. *doi:10.1016/j.soilbio.2015.09.005*.

[13] Druille, M., Cabello, M.N., Omacini, M., and Golluscio, R.A. 2013. *Glyphosate reduces spore viability and root colonization of arbuscular mycorrhizal fungi.* APPLIED SOIL ECOLOGY, 64: 99–103; doi: *https://doi.org/10.1016/j.apsoil.2012.10.007*.

[14] Hamel, C. 2004. *Impact of arbuscular mycorrhizal fungi on N and P cycling in the root zone.* CAN. J. SOIL SCI. 84(4): 383–395.

above and below ground facilitates the ability of organic systems to tolerate, adapt to, and recover from extreme weather conditions.

- High levels of organic matter in organic farm soils increase soil water retention, porosity, infiltration, and prevent nutrient loss and soil erosion. These soil properties make agriculture more resistant to flooding, drought, high winds, and the loss of soil organic carbon.
- Diverse cropping and intercropping on organic farms keep pest and predator relationships in check, decreasing crop susceptibility to insect pests and disease and increasing crop resiliency and adaptability to the extreme variabilities of climate change.
- "Given its potential for reducing carbon emissions, enhancing soil fertility and improving climate resilience, Organic Agriculture should form the basis of comprehensive policy tools for addressing the future of global nutrition and addressing climate change." [15]

As Congress debates effective strategies to address the threat of global climate change, we believe the science shows that organic agriculture can be part of the solution to this challenge. In addition, we strongly believe that conventional plant breeding to develop cultivars that are regionally adapted to changing climates can help to increase carbon sequestration on farms and to mitigate against the risks associated with climate change. Additional research and education funding is critical to expanding our knowledge about the role of farming practices in addressing climate change challenges.

Thank you for the opportunity to provide this testimony on behalf of the National Organic Coalition member organizations:

Beyond Pesticides
Center for Food Safety
Consumer Reports
Equal Exchange
Food & Water Watch
Maine Organic Farmers and Gardeners Association
Midwest Organic and Sustainable Education Service
National Co+op Grocers
Northeast Organic Dairy Producers Alliance
Northeast Organic Farming Association
Ohio Ecological Food and Farm Association
Organic Seed Alliance
PCC Community Markets
Rural Advancement Foundation International—USA

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[15] International Federation of Organic Agriculture Movements (IFOAM). *https://www.ifoam.bio/en/advocacy/climate-change*.