Regional Approaches to Climate Change for Pacific Northwest Agriculture

Climate Science Northwest Farmers Can Use

REACCH
Regional Approaches
to Climate Change –
PACIFIC NORTHWEST AGRICULTURE

www.reacchpna.org

February 15, 2014 - February 14, 2015

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Welcome to REACCH: Project overview

Sanford Eigenbrode (sanforde@uidaho.edu) UI, Project Director

Farmers are the world's original integrators. Successful modern farming requires a good understanding of the components and processes of entire production systems and how they interact. The tremendous importance of cereal-based agriculture greatly affects local economies and influences regional culture and communities. Some of the most productive wheat land in the world can be found in the inland Pacific Northwest (PNW) region, which includes northern ID, north-central OR, and eastern WA. The REACCH project is designed to enhance the sustainability of cereal production systems in the inland PNW under ongoing and projected climate change, while contributing to climate change mitigation by reducing emissions of greenhouse gases. REACCH is a comprehensive response to the implications of climate change for the already challenging task of managing cereal production systems for long-term profitability. Scientists from many disciplines, including engineering, climate science, agronomy, sociology, and economics, are working together to ensure greater relevance of the information provided to regional cereal farmers and their associates. Our aim is to conduct the best agricultural science relevant to regional climate projections and the needs for adaptation and mitigation, and to extend this science to our diverse group of stakeholders.

Our fourth annual report for REACCH provides a compendium of 63 short reports representative of activity underway within the REACCH project. The report has four objectives: (1) to showcase the breadth of our work pertaining to climate and cereal production systems of the region, (2) to set the stage for realizing the benefits of this work to producers and other stakeholders beyond the term of our grant from the National Institute of Food and Agriculture (NIFA), (3) to highlight important current collaborators and future partners that will help us to maximize these benefits, (4) to provide information useful to our diverse stakeholders, including farmers, other agricultural industry personnel, teachers, policymakers, and general citizens of the region. This report is a part of our ongoing conversations among all of these groups. We continue to be proud of what REACCH is accomplishing and remain deeply committed to producing results that will be useful to Pacific Northwest agriculture.

REACCH team members convene yearly with collaborators, producers, our Stakeholder Advisory Committee, and our Scientific Advisory Panel. In year 3, we gathered in Richland, WA. Join us in Moscow, ID, March 4 to 6, 2015, for our next meeting. Photo by Brad Stokes.

REACCH audiences

Because climate change and agriculture affect everyone, REACCH recognizes the importance of considering how our research, education, and outreach efforts influence multiple audiences. In most cases, these efforts apply to multiple public and private sectors, which will be indicated throughout this report by the following icons. These icons are a guide highlighting key interest areas. Many of our readers will have multiple interests throughout the report.

Grower/Agricultural Industry

Scientists

Educators

Policy Makers

General Public

Partners and collaborators

- 4 institutions
- 3 states
- 25 project investigators
- 58 graduate students and postdocs
- 12 academic departments at three land-grant universities, and the U.S. Department of Agriculture Agricultural Research Service.

Scientific Advisory Panel members: Karen Garrett, University of Florida; Matt Baker, Texas Tech University; Phil Robertson, Michigan State University; Richard Howitt, UC Davis; Rich Jones, Pacific Northwest Direct Seed Company; Senthold Asseng, University of Florida.

Stakeholder Advisory Committee members: A diverse group of local producers and people involved in climate and sustainable agriculture nongovernmental organizations, grower support industries and associations, supply companies and cooperatives, state agencies, tribal associations, federal agencies, and K-12 teachers.

REACCH Research Areas: Modeling Framework, Greenhouse Gas Monitoring, Cropping Systems, Economic and Social Factors, Biotic Factors, Education (K-12, undergraduate, graduate), Extension, Cyberinfrastructure, Data Management and Technology, Agroecozone Modeling, and Life Cycle Analyses.

Cook Farm student harvest crew celebrates after a long day's work. Photo by Dave Huggins.

Win-win scenarios for farm and climate

Bill Pan (wlpan@wsu.edu) WSU and Kristy Borrelli UI

Efforts to achieve climate adaptation and mitigation in regional cropping systems are coupled and can present potential short- and long-term, "win-win" scenarios for both agriculture and the environment.

Management Strategies	Short-Term Benefits (1-10 years)	Long-term Benefits (40+ years)
Reduced tillage/Direct seeding	• Decreased soil erosion and nutrient runoff • Increased SOM and improved soil quality • Increased nutrient cycling and storage	• Reduced CO_2 emissions by storing soil C
Crop Intensification – Reduce fallow	• Increased food, fuel feed production • Increased farm productivity and income	• Fixed CO_2 removes it from atmosphere by increasing PS • Increased straw biomass and soil C sequestration
Crop Diversification – Legumes	• Improved control of pests and grass weeds using a broadleaf crop in rotation • Reduced N fertilizer costs using BNF	• Reduced GHG emissions and natural gas use during N fertilizer production • Reduced reactive soil N that leads to N_2O emissions
Crop Diversification – Oilseeds	• Improved control of pests and grass weeds using a broadleaf crop in rotation • Improved soil structure and water infiltration with canola's strong taproot • Glyphosate resistant canola is only RR crop that can be grown in PNW rotations	• Increased net productivity, PS and C fixation • Reduced atmospheric CO_2 through increased soil C sequestration • Reduced N_2O emissions and improved N cycling • Avoid summer heat and drought stress with a short season crop
Customize wheat class and variety to AEZ	• Potential to improve protein premiums • Improved overall regional wheat quality and market reputation • Match heat and drought tolerance to AEZ • Potential to adapt to pest variability	• Improved resource efficiency and lower loss, as crops are better suited to environment • Tolerant varieties are more adaptable to climate change and associated concerns
Prescription N management	• Reduced N fertilizer costs • Reduced N over-fertilization that can reduce yields • Reduced N runoff and loss	• Reduced GHG emissions and natural gas use during N fertilizer production • Reduced reactive soil N that leads to N_2O emissions
Recycled organic byproducts	• Increased SOM and improved soil quality • Reduced N fertilizer costs • Recycled valuable nutrients • Reduced landfilling biological wastes	• Tightened global nutrient cycles reduces N_2O and CO_2 emissions • Reduced GHG emissions and natural gas use during N fertilizer production

Abbreviations: SOM = soil organic matter; C = carbon; CO_2 = carbon dioxide; PS = photosynthesis; N = nitrogen; BNF = biological nitrogen fixation; N_2O = nitrous oxide; AEZ = agroecological zones; GHG = greenhouse gases; RR = Roundup™ ready.

Metric conversion table

From	To
1 hectare	2.47 acres
1 acre	0.41 hectare
1 pound	454 gram
1 pound	0.45 kilogram
1 kilogram	2.2 pounds
1 foot	0.31 meter
1 meter	3.3 foot
1 inch	2.54 centimeters

Climate Trend	Observed Change (1985-2014) vs. (1895-1984)	Projected Change (2040-2069) vs. (1971-2000)	Impacts
Warmer Winters	+1.3F	+5.2F	Reduced snowpack, increased winter runoff, reduced overwinter mortality
Warmer Springs	+1.3F	+5F	Earlier greenup and plant maturation, longer freeze free season
Warmer Summers	+1.2F	+6F	Increased heat stress and evapotranspiration
Wetter Springs	+12%	+5%	Offset increased water use by plants, increased potential for water logged soils
Drier Summers	-3%	-9%	Increased drought stress

Obs change is from NCDC data using an average of WA/OR/ID

Projected change are from MACA RCP8.5 data and represent the multi-model mean change for the NW US covering WA/OR/ID and western MT.

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Addressing the agricultural impacts and vulnerabilities of climate change

Sonny Ramaswamy (sonny@nifa.usda.gov), Director, National Institute of Food and Agriculture

The U.S. Global Change Research Program's National Climate Assessment of 2014 observes that key vulnerabilities to climate change in the United States include increasing temperatures across the country, less rapid warming in coastal regions of the continental United States compared to inland regions, more frequent heat waves across North America, and more intense precipitation and frequent flood-producing storms. In light of these predicted impacts and vulnerabilities, particularly in agricultural, forestry, and rangeland production systems but also in natural systems, the report calls on federal and state agencies and governments to be prepared to deal with these shifts in climate, and to develop approaches to adapt to and mitigate the impacts of these shifts.

IMPACT

Climate change is one of several "wicked" problems facing agriculture and food production across the globe. In light of the predicted impacts and vulnerabilities associated with shifts in climate, federal and state agencies and governments are improving modeling and scientific methodologies and outreach methods. These will provide decision makers with science-based tools and outreach materials that will help them make effective policies, address immediate local needs, and ensure the long-term sustainability of food and fiber production.

Agricultural and forestry producers, land managers, and other decision makers need information, technologies, and decision-support tools regarding greenhouse gas (GHG) mitigation, adaptation strategies, and policy outcomes. Crop, animal, forest, range, and even urban and rural management approaches must take climate variability into account to improve long-term sustainability. The potential for forest and agricultural lands to serve as carbon sinks and to reduce GHG emissions must be quantified to support sound policies and environmental markets. Outreach and extension networks must be implemented to incorporate climate change mitigation and adaptation strategies into management practices and to support restoration projects, planning, interventions, and prescriptions with scientific findings.

To address these needs, the National Institute of Food and Agriculture's (NIFA) Agricultural Science for Climate Variability and Change Programs include:

- Forecasting climatic stress at relevant scales. It is critically important to understand current projections of climatic change, and to be able to anticipate the causes and impacts at regional and national scales. The impacts on local individual landowners are exceedingly difficult to predict.

Sonny Ramaswamy, Director, National Institute of Food and Agriculture.

- Creating tools to identify and predict climate change impacts at appropriate time and spatial scales. It is difficult to definitively decouple impacts that can be attributed to climate change from other factors that traditionally affect agronomic operations, and we need better tools and metrics to measure these so that adaptation and mitigation strategies are more effective.
- Projecting how and where climate change is most likely to influence risk pathways for pests, notably agricultural diseases; forest, crop, and livestock pests; and food-borne pathogens that could potentially affect global agricultural systems.
- Addressing uncertainties in methodologies (empirical and process based) used to evaluate changes in climate with specific resource impacts and the feedbacks of interventions and actions for adapting to and mitigating the climate system and the environment.
- Increasing our understanding of climate dynamics and uncertainties for policy and strategic planning. Climate dynamics are extremely complex and are associated with a great deal of uncertainty. New approaches are needed to reduce uncertainty and incorporate what cannot be eliminated into approaches for sustainable production.
- Developing usable information and effective communication. Public perceptions of climate change can create resistance to the importance of climate change education. Information needs to be presented in a manner that stakeholders can identify, understand, and accept more easily.

As part of its strategy to address different sectors of the climate change portfolio, NIFA has developed a set of applied climate tracks that identify major areas of application of research, education, and extension activities. Each track has a set of achievable outcomes during the next 10 years, which were used to populate the outcomes of logic models as part of a roadmap for NIFA's climate change portfolio. These tracks and outcomes include:

- Agroecosystem production and resource management
- Genomics and breeding
- Social and economic dimensions
- Formal and informal education
- Extension and outreach

In addition, NIFA proposes to measure in its portfolio the public, animal, plant, and environmental health impacts of climate change as related to food, agricultural, forestry, rangeland, and natural systems.

REACCH is one of three NIFA Climate Change and Variability Coordinated Agricultural Projects (CAPs). The CAPs are large efforts that integrate three or more of these dimensions into transdisciplinary efforts that span disciplines, regions, and institutions. They are breaking new ground for NIFA in terms of the scope of their long-term mission for science, education, and extension efforts. These projects represent examples of the new call for convergence of disciplines and sectors to address societal challenges (Figure 1). Each project is charged with initiating efforts that will lead to improved carbon sequestration, nitrogen use efficiency, and resilience to changing climates well into the 21st century. Project leaders and NIFA program leaders are working together to monitor project efforts to ensure that they are meeting these needs. NIFA is pleased with the accomplishments being made, and is encouraged that REACCH and the other CAPs will generate the envisioned information and impacts.

The larger context of the work by the CAPs is broad. Not only are these projects addressing diverse agricultural systems, from Pacific Northwest wheat production (REACCH) to Midwest corn (Sustainable Corn) and Southeast plantation pine (PINEMAP), they are also part of the necessary global response to the challenges of food and fiber production as climates change. Production systems are complex technologically, socially, and economically. Responding to changing climates involves addressing "wicked" problems in which diverse stakeholders, from farmers to national policy makers, must integrate different perspectives in order to delineate effective actions.

Climate change is just one specific global challenge. It is our hope that the efforts of NIFA-funded projects can help improve how production systems respond to the challenges ahead as populations grow, along with their per capita demands for more protein-rich animal foods, goods, and higher living standards. Contributing to solutions for these wicked problems will indirectly, but significantly, improve the well-being of U.S. farmers, their families, and their communities.

Figure 1. *Complex problems that negatively affect natural and managed systems are often transdisciplinary in nature, without a single solution. It is therefore necessary for state and federal governments, land managers, educators, and other decision makers to work together and consider each aspect that can improve the long-term sustainability of these systems.*

In the coming months and years, we anticipate that the good work ongoing in the U.S. Department of Agriculture NIFA CAPs and related projects will bear fruit in the form of better understanding of systems, better platforms for continued collaboration across institutions, and better approaches and technologies to address environmental and climatic challenges.

Sanford Eigenbrode (left) discusses Northwest agriculture with Sonny Ramaswamy, current director director of the USDA National Institute of Food and Agriculture during a visit to Moscow, ID, in July 2014. Photo by Joe Pallen.

REACCH and the REACCH legacy

Sanford Eigenbrode (sanforde@uidaho.edu) UI, Project Director

REACCH is one of more than 30 projects funded by the U.S. Department of Agriculture's (USDA) National Institute of Food and Agriculture (NIFA) and its Climate Variability and Change Program, which is designed to address the problems anticipated for agriculture across the nation due to changing climates. NIFA's programs are part of a broader effort across the USDA that includes activities within the Agricultural Research Service (ARS), the U.S. Forest Service (USFS), the Risk Management Agency (RMA), the Animal Plant Health Inspection Service (APHIS), the Long-Term Agroecosystem Research (LTAR) Network, and the newly established USDA Climate Hubs. As NIFA Director Sonny Ramaswamy noted in a visit to the Palouse this past summer, this emphasis acknowledges that climate change is one of several "wicked" problems facing agriculture and food production at home and across the globe. The USDA is committed to leading efforts to mitigate and adapt to climate change, drought, and extreme weather in agriculture and forestry. As outlined by Director Ramaswamy (see page 2 of this report) and USDA Secretary Tom Vilsack, these efforts will include addressing six challenges. This, our fourth annual report, shows how REACCH and its partners are addressing these six challenges and laying the groundwork for continuing to address them into the coming decades.

IMPACT

The REACCH project is taking an unprecedented, coordinated, and integrated approach to supporting Pacific Northwest cereal production. Although our research, education, and extension efforts address topics ranging from nitrogen use efficiency to insect pest management, all is done in the context of the whole production system. In this respect, the project aligns with the integrating approach that farmers use to manage their operations. The project will end in 2016, but its influence will continue over the time scales relevant to long-term sustainability of agriculture in our region.

1. Building tools to identify and predict climate change impacts. Climate scientists in REACCH, at all three of our land-grant partners, have built detailed downscaled climate models based on the latest global models and are capable of projecting conditions at a 2.5-mile grid size. These in turn are being used to project responses of our current cereal cropping systems in terms of yield. Collaborative efforts across REACCH are allowing downscaled climate models to be coupled with cropping system models to anticipate changes in potential yields under different types of production systems. Using data available from the National Agricultural Statistics Service, we have generated dynamic maps of production systems (agroecological classifications) that show how yields vary over time, in part in response to climate. This is an invaluable baseline for detecting changes over the long term. These and other survey data being generated by REACCH are being cataloged and stored so that they can be readily accessed to reveal responses as climate changes in the Pacific Northwest (PNW).

2. Projecting how and where climate change may affect pests. Ongoing work in REACCH is using the downscaled climate models described in item 1 to project changes in the suitability of cereal pests, including the cereal leaf beetle (see the Year 3 annual report), aphids, and weeds such as downy brome and pathogens (see the Year 3 annual report, https://www.reacchpna.org/whatsnew/reports/). The models can also generate current degree-day models for phenology of pests and weeds, which will be incorporated into decision support tools for producers. Current and historical sampling data, coupled with climate information, can inform these projections.

3. Addressing uncertainties in methodologies. Climate change and variability present significant challenges because projected trends indicate that agriculture could be strongly affected, but the variability in climate projections is necessarily high. At each level, from selection of emission scenarios to selection of climate models and downscaling approaches and assessing how systems respond to climatic variables, there is inherent uncertainty. Our approach in REACCH is to ensure that this uncertainty is accounted for fairly in the science and in our discussions and communications to stakeholders. As climate science pertaining to the PNW advances, our team is on the front lines.

4. Increasing understanding of climate dynamics and uncertainties for policy and planning. Our project is engaged in activities designed to inform policy that could improve agriculture's resilience to climate change in the PNW.

5. Reducing the use of energy, nitrogen fertilizer, and water and increasing carbon sequestration through resilient agriculture and forest production systems. A principal theme of REACCH is continuing the long-standing effort by scientists in our region to help producers preserve soil carbon and improve the efficient use of fertilizers. Team members are documenting the effects of tillage practices on carbon in soils, on emissions of CO_2 and N_2O from production systems, and on the presence of nitrate in subsurface water.

6. Developing usable information and effective communication. Our project depends on excellent communication with the public and with stakeholders and on producing information that is useful. Although much of the science concerns trends and projections well into the 21st century, we are also producing information on current production practices and the management of pests and diseases that is useful today. Our outlets include online information, publications, informational videos, and webinars.

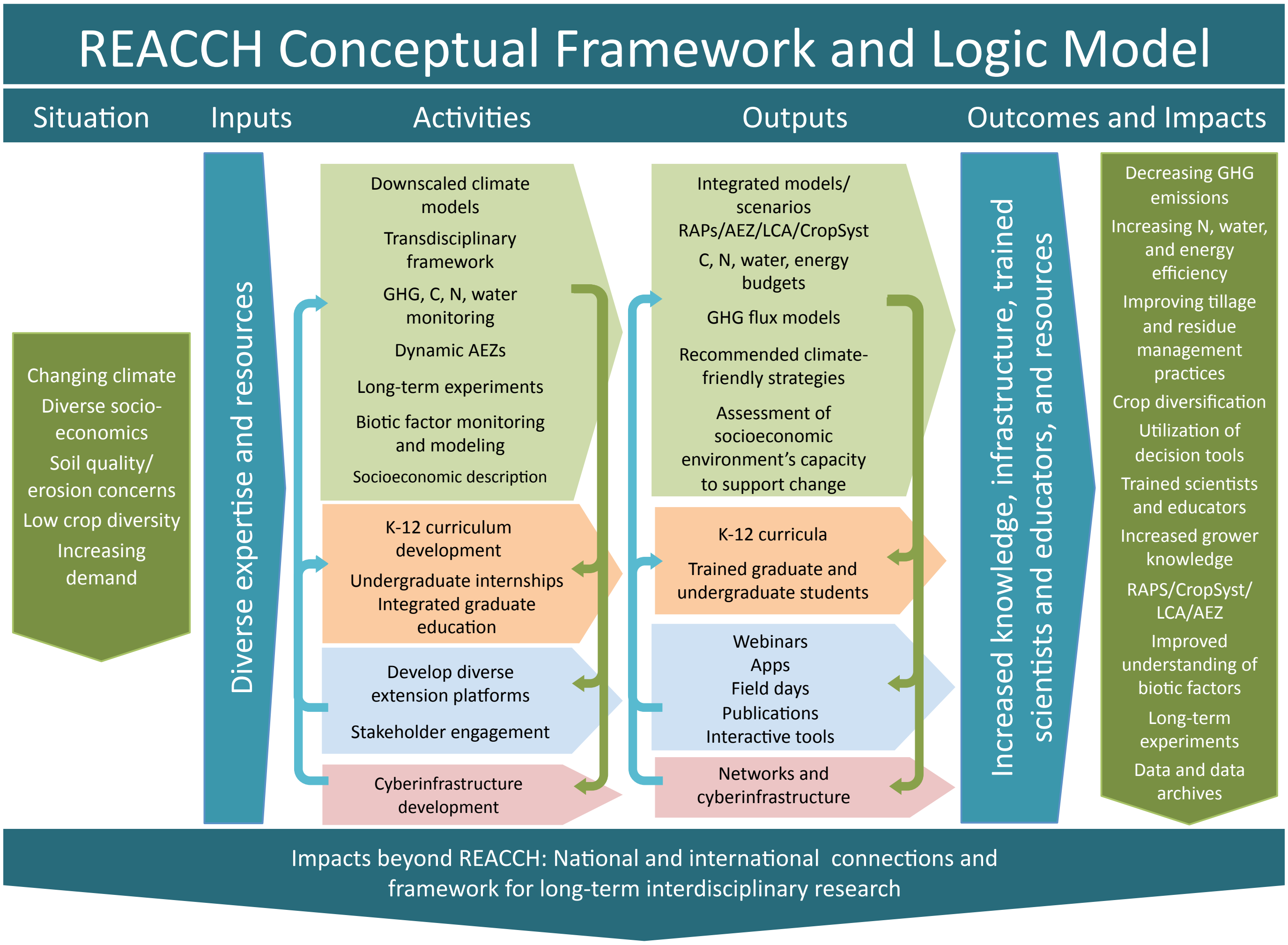
REACCH is a large Coordinated Agricultural Project (CAP), with $20 million in funding over five years. Unlike other NIFA projects, CAPs are charged with addressing the complexity of climate change as it affects entire agricultural systems, and they are unprecedented in their integrative scope. Each of our scientists and students is contributing to one or more of the six challenges listed here, but all of us are also working in the broader context of a fully integrated project (Figure 1). We can all locate our work within this framework and articulate the connections and synthesis in which we are engaged. Our students are exposed to different aspects of the work through collaborative cross-disciplinary projects.

The other two NIFA CAPs are Sustainable Corn, led by Iowa State University, and PINEMAP, led by the University of Florida. Since their inception in 2011, the CAPs have worked closely to collaborate with and support one another to ensure that all three projects are successful. For an overview of what the three CAPs have accomplished see Eigenbrode et al. in the November/December 2014 issue of the *Journal of Soil and Water Conservation*.

Although motivated by a long-term vision of sustainable agricultural production, NIFA's CAPs and smaller climate projects are not in themselves long-term efforts; funding for REACCH will end during 2016. Toward the longer-term goals, REACCH is establishing the requisite collaborative frameworks, cyberinfrastructure, long-term experiments, conceptual framework, and capacity for continued efforts in the region. In our final two years as a project, partnerships with ongoing and beginning efforts addressing climate change and other threats to the sustainability of cereal production in our region will be critical. To reflect that emphasis, a special section of this annual report contains reports from many of these key partners. Representatives of these projects will participate in the fourth annual meeting of the REACCH project in March 2015 to delineate these collaborative efforts.

The REACCH project will help ensure that future generations in our region will have sustainable agricultural systems. Photo by Jillian Blume.

Figure 1. *REACCH conceptual framework and logic model.*



Cook Agronomy Farm LTAR site: Knowledge-intensive precision agroecology

Dave Huggins (david.huggins@ars.usda.gov) USDA-ARS

A national LTAR Network is born

In 2011, the Washington State University R. J. Cook Agronomy Farm (CAF), near Pullman, WA, was designated by the U.S. Department of Agriculture (USDA) as one of ten locations to initiate a national Long-Term Agroecosystem Research (LTAR) Network. Establishment of the LTAR Network was a response to a "call for action" voiced by many in agriculture who recognized that certain questions require a long-term, systems perspective to adequately assess the trade-offs and consequences of different agricultural strategies. In 2014, eight more locations were added to the national network, and the initial ten locations received base (annual) funding to carry out long-term research goals (Figure 1). The selection of CAF as part of the LTAR Network was an outgrowth of the REACCH project and other long-term regional partnerships among universities, growers, agribusiness, state agencies, and the USDA.

Currently, agriculture faces tremendous challenges in meeting multiple, diverse societal goals, including (1) providing a safe and plentiful food supply; (2) adapting to and mitigating climate change; (3) supplying sources of bioenergy; (4) improving water, air, and soil quality; and (5) maintaining biodiversity. An overall goal of the national LTAR Network is to enable long-term, transdisciplinary science across farm resource regions to address the following four priority areas of concern: (1) agroecosystem productivity, (2) climate variability and change, (3) conservation and environmental quality, and (4) socioeconomic viability and opportunities. A key expectation of the LTAR Network is that research results will help address critical challenges facing agriculture.

IMPACT

Long-term, transdisciplinary agricultural research is essential if agriculture is to meet multiple, diverse societal goals, including food supply, climate change adaptation and mitigation, bioenergy, water/air/soil quality, and biodiversity. In 2011, the Washington State University R. J. Cook Agronomy Farm (CAF) was designated by the U.S. Department of Agriculture as one of ten sites within a national Long-Term Agroecosystem Research (LTAR) Network, and in 2014 CAF received annual base funding for this effort. The CAF site of the LTAR Network is regional in scope, following in the footsteps of REACCH with a focus on supporting long-term research into cropping systems and precision agricultural systems through building of research capacity and support for graduate education and outreach efforts. This funded, long-term effort will provide a cornerstone for supporting transdisciplinary research partnerships and will increase the region's competitive capacity to pursue a rich, grower-oriented research portfolio.

The R. J. Cook LTAR Site

Drowning in data and starving for knowledge, agricultural decision makers require evidence-based information to enlighten sustainable intensification. The agroecological footprint of the CAF LTAR site is embedded within 23 million acres of land with diverse uses, primarily cropland (7.2 million acres) and rangeland (13 million acres) that span a wide annual precipitation gradient (6 inches through 55 inches) with diverse social and natural capital (Figure 2). Sustainable intensification hinges on the development and adoption of precision agroecological practices that rely on meaningful spatiotemporal data relevant to land use decisions at within-field to regional scales. Specifically, the CAF LTAR site will contribute to a scientific foundation (socioeconomic and biophysical) that will enhance decision support for precision and

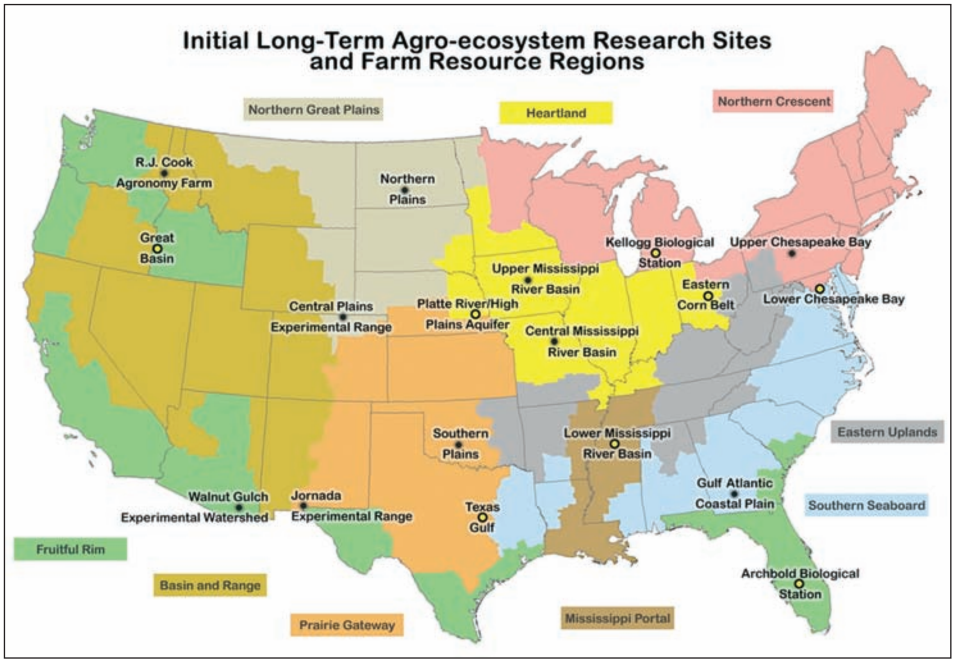


Figure 1. *Locations of the Long-Term Agroecosystem Research Network sites (2014).*

conservation agriculture and synergistic cropping system intensification and diversification. Long- and short-term perspectives that recognize and assess the trade-offs inherent in any land use decision will be considered so as to promote the development of more sustainable agricultural systems.

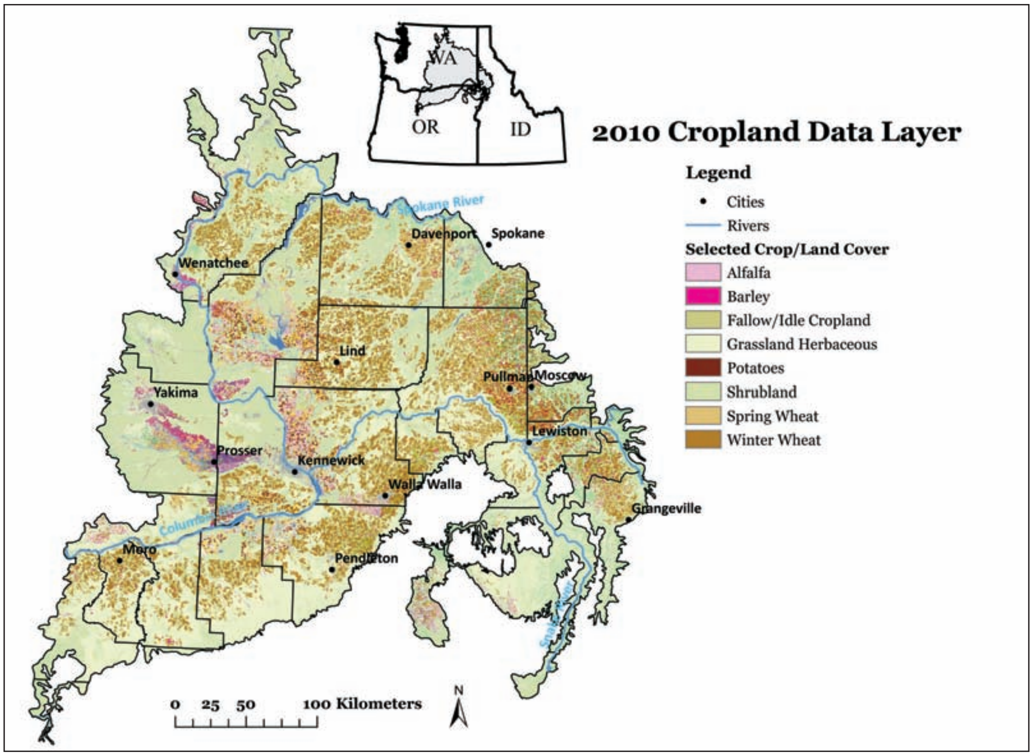


Figure 2. *Cropland data layer for the REACCH region (National Agricultural Statistics Service, 2010).*

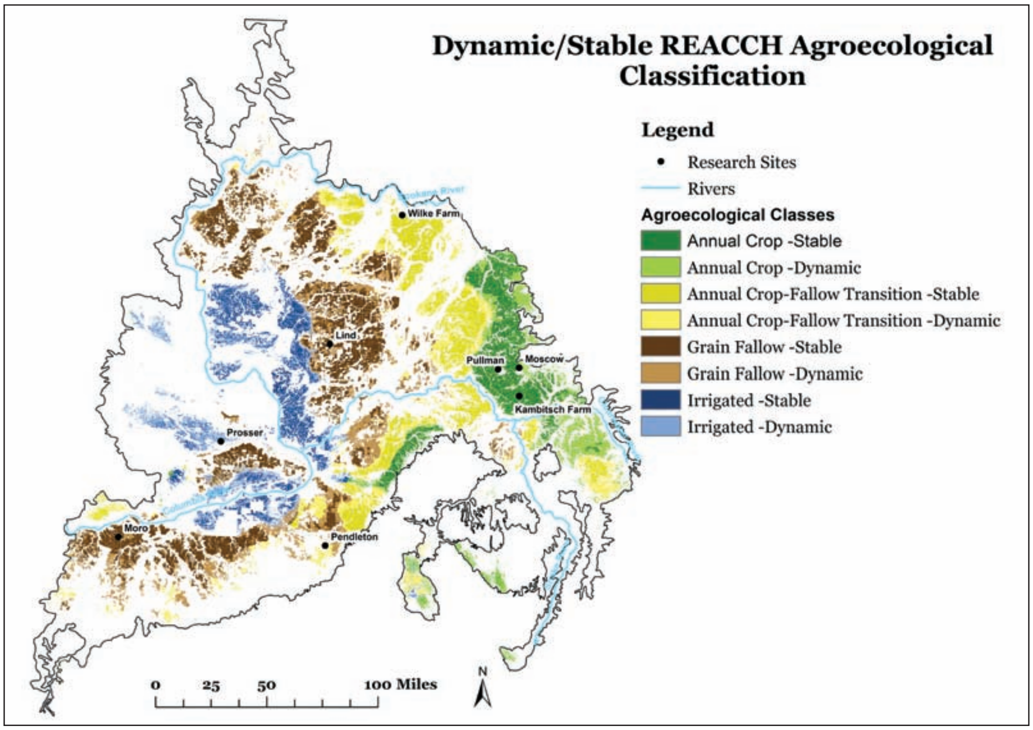


Figure 3. *Stable and dynamic agroecological classes (AECs) for the REACCH region based on 2007 through 2013 cropland data layers.*

Precision agriculture

Research into precision agriculture (PA) will be led by efforts at the CAF and Wilke Farm (Davenport, WA) experiment stations, as well as at cooperating on-farm watershed locations. The research will augment past and current PA studies and will include assessing long-term cropping system cycles and flows of nutrients, water, carbon, and other biotic and abiotic factors, using a suite of PA technologies, including remote and proximal sensing coupled with crop- and soil-based mass-balance approaches. The research will emphasize evaluation criteria and metrics associated with long-term agroecosystem provisioning, supporting, and regulating services.

Conservation agriculture

Comparisons of greenhouse gas (GHG) fluxes associated with conventional and no-tillage agriculture, including eddy-covariance flux towers coupled with automated static chambers initiated by REACCH, will be continued. Long-term monitoring and characterization of soil health and water quality at the CAF site and other sites will also continue, contributing to our understanding of the long-term impacts of agricultural practices on natural resources. On-farm evaluations will involve select farms and ranches throughout the CAF LTAR footprint that will allow researchers to assess conservation agriculture (CA) and PA, following design guidelines for on-farm research.

Opportunities for flex cropping that include cropping system diversification and intensification options will be assessed at long-term sites within major dryland agroecological zones, including locations in northeastern OR, eastern WA and northern ID (Figure 3). Regional infrastructure (e.g., agweathernet) will be augmented and combined with process-oriented crop modeling and economic evaluation to aid flex-cropping decisions and assessment. Cropping system assessment will emphasize agroecosystem provisioning, supporting, and regulating services using transdisciplinary approaches.

REACCH: Useful, collaborative research for the Pacific Northwest

John Foltz (jfoltz@uidaho.edu), Dean, College of Agricultural and Life Sciences, UI
Ron Mittelhammer (mittelha@wsu.edu), Dean, College of Agricultural, Human, and Natural Resource Sciences, WSU
Daniel Arp (dan.j.arp@oregonstate.edu), Dean, College of Agricultural Sciences, OSU

As deans for the three land-grant universities in the Pacific Northwest (PNW), we are very supportive of the U.S. Department of Agriculture funded project Regional Approaches to Climate Change in Pacific Northwest Agriculture (REACCH – PNA) and the continuation of research, education, and outreach in the focus area of the project.

IMPACT

The REACCH project is part of a broader regional collaborative effort that includes our three land-grant universities. A message from the deans of the agricultural colleges in these universities emphasizes the commitment to current and future benefits of the REACCH project for the wheat producers of our region.

In anticipation of the termination of National Institute of Food and Agriculture (NIFA) funding for this project in 2016, we reconfirm our commitment to the research objectives of this important project—"ensuring that agriculture and grain production will endure future climate change." This project has been a great example of the collaborative relationship that our universities and our respective colleges of agriculture (variously named) have in all three areas of our mission: research, teaching, and extension. Over 100 scientists and students from our institutions are participating in this important project. Here we outline how the REACCH mission aligns with the mission of our respective institutions, and how we will ensure continuity into the future.

John Foltz, Dean, College of Agricultural and Life Sciences, UI.

The University of Idaho has outlined in its most recent strategic plan that it will move forward with Programs of Distinction (PODs), which will allow the college to be more focused in its intent and the direction of its efforts. Specifically, the Cereals POD will allow the College of Agricultural and Life Sciences to continue much of the important work initiated by the REACCH project. Climate change will challenge existing cereal end-use quality, yield, pest management, and agronomic practices. Additionally, the REACCH project was instrumental in the creation of a second POD—Human, Natural, and Managed Ecosystems. This POD focuses primarily on ecosystems under stress, ecosystem services, and watershed management. Continuation of the REACCH project goals is key to many of the priorities of the college to help prepare agriculture for continued climate change.

Similarly, at Washington State University, the College of Agricultural, Human, and Natural Resource Sciences (CAHNRS) has identified two new Pinnacles of Excellence that will guide future research emphases and investments over the next decade. One of these is Water Resource Management and Climate Change. Numerous faculty within CAHNRS are actively pursuing research at the intersection of water, climate, agriculture, and urban living throughout the state, the PNW, and the world. CAHNRS also has field-based extension faculty and staff that are actively addressing issues at the intersection of water and climate, including marine water-quality issues in support of shellfish production and Puget Sound ecosystem recovery efforts; freshwater water-quality issues, including stormwater runoff, septics, and livestock effects on water quality; water-quality and water-quantity issues through the Master Gardener program; and many other related programs. CAHNRS faculty are essential to integrated interdisciplinary research efforts being pursued related to water and climate issues through the Center for Environmental Research, Education, and Outreach (CEREO); the State of Washington Water Research Center (SWWRC); the Washington Stormwater Center (WSC); and the Center for Sustaining Agriculture and Natural Resources (CSANR), which provide a nexus for interdisciplinary research and outreach for the full scope of water- and climate-related issues. Continuation of the REACCH project goals is central to many of CAHNRS' priorities for preparing agriculture, as well as society more generally, for continued climate change.

Ron Mittelhammer, Dean, College of Agricultural, Human, and Natural Resource Sciences, WSU.

Oregon State University (OSU) and its College of Agricultural Sciences (CAS) are engaged in research and education on agricultural and managed ecosystems and understanding the human

Daniel Arp, Dean, College of Agricultural Sciences, OSU.

interactions, the biological and agronomic drivers, and the connections to healthy and sustainable outcomes. OSU's strategic plan centers on three "healthies"—healthy planet, healthy people, and healthy economics—in its commitment to student success for undergraduates, graduate students, and lifelong learners. The REACCH project and the CAS goals for addressing a changing climate and the continued sustainability of our food systems are in sync with OSU's objectives. College faculty are exploring the opportunities and challenges of a changing climate, new technologies, and data-driven policies for the agricultural and food sectors and are finding better ways to communicate this information to students and stakeholders. Through enhanced partnerships with decision makers (growers, food system suppliers, and policy makers), OSU and CAS are addressing both adaptation and mitigation pathways, and through innovation in educational and outreach efforts, they are ensuring a workforce capacity to meet increasing needs to provide for a stable and sustainable food supply. Development of online web-based decision tools for agricultural producers, supported by the REACCH project and by targeted investments made by OSU and CAS, is an example of translating often technical climate research into readily understandable information for assessing adaptation alternatives and farm-scale investments.

Lauren Young, WSU MS cropping systems student, analyzes soil samples for nitrogen in order to make nitrogen fertilizer recommendations to producers. Photo by Stephen Cole.

REACCH graduate students, colleagues and interns taught and helped at our Teacher Workshop in Pendleton, Oregon. Students Nicole Tautges (center) taught weed identification and Allison Buiser (right) was an intern on precision agriculture technologies—both themes of the teacher workshop. Photo by Leigh Bernacchi.

Bioclimatic-driven future shifts in dryland agroecological classes

Harsimran Kaur (harsimran.kaur@wsu.edu) WSU, Dave Huggins USDA-ARS, Rick Rupp WSU, John Abatzoglou UI, Claudio Stockle WSU, and John Reganold WSU

Climate change may result in substantial geospatial shifts in dryland cropping systems or agroecological classes (AECs). To analyze these potential shifts, we first successfully predicted current AECs based on land use/cover using bioclimatic variables. We then used identified bioclimatic AEC predictors in conjunction with future climate scenarios to project potential shifts in dryland AECs for the coming century.

IMPACT

Our analysis found that climate change could cause substantial increases in the geospatial extent of the annual crop-fallow transition agroecological class (AEC) at the expense of the annual crop AEC. This shift could negatively affect cropping system diversification and intensification, soil organic matter, and soil vulnerability to erosion processes in the future.

Since 2007, the National Agricultural Statistics Service (NASS) has annually produced a cropland data layer of actual land use/cover (Figure 1) for the continental United States. We used the available annual cropland data layers to classify the REACCH study region into four major AECs: (1) dryland annual cropping (limited annual fallow), (2) annual crop-fallow transition (e.g., three-year rotations with fallow every third year), (3) grain-fallow (e.g., two-year rotation), and (4) irrigated. Our main objectives were to (1) identify important bioclimatic predictors that can discriminate among current dryland AECs and (2) use identified bioclimatic variables with future climate scenarios to predict potential shifts in dryland AECs. To achieve these objectives, we used current AECs (2007 through 2013) in the statistical variable selection process (discriminant analysis) to identify bioclimatic variables that significantly affect actual land use. Geographic information system software (ArcGIS) was integrated with statistical software "R" to process the AEC and climate data.

Table 1. *Number of pixels (2.5 × 2.5 miles) classified in each AEC for present and future scenarios.*

	Stable AECs			Dynamic AECs		
Time period	AC*	AC-T*	GF*	AC	AC-T	GF
Present (2007–2013)	195	194	530	116	197	260
Predicted present	196	184	539	100	192	281
Correctness (%)	92.3	82.0	97.9	60.3	65.5	88.8
Future scenario (RCP -4.5)						
2026–2035	154	221	544	51	208	314
2056–2065	117	280	522	45	202	326
2086–2095	104	293	522	17	309	247
Future scenario (RCP -8.5)						
2026–2035	146	227	546	51	203	319
2056–2065	83	313	523	23	281	269
2086–2095	35	401	483	10	309	254

*AC: Annual crop
*AC-T: Annual crop-fallow transition
*GF: Grain fallow

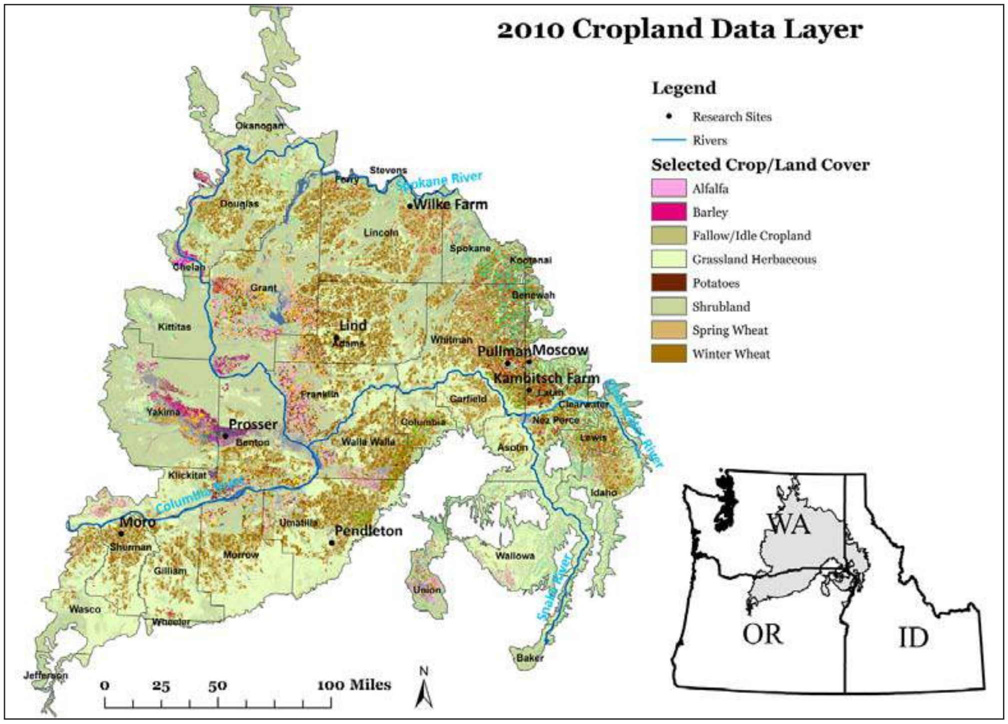


Figure 1. *Cropland data layer for the REACCH study area (National Agricultural Statistics Service, 2010).*

We scaled AEC data to climate data (2.5 × 2.5 miles) using the default nearest neighbor method in ArcGIS. To understand year-to-year dynamics between AECs, we further subcategorized classes into stable and dynamic AECs. Stable AECs did not change into any other class from 2007 to 2013. In contrast, dynamic AECs changed one or more times from 2007 through 2013 (Figure 2).

We calculated bioclimatic variables important in Mediterranean climates using actual 30-year (1981 to 2010) precipitation and temperature data. To reduce redundant information, we dropped variables using stepwise variance inflation in “R” software. We then conducted stepwise statistical discriminant analysis with “leave one out” cross-validation on the retained variables for stable and dynamic AECs. The preliminary analysis identified annual precipitation, growing degree days (January 1 through May 31), and percentage precipitation during March, April, and May and during September, October, and November as key bioclimatic predictors of AECs. Overall cross-validated misclassification error was 6% and 25% for stable and dynamic AECs, respectively. Finally, we used future climate data from 14 different global climate models to calculate the identified bioclimatic variables for three different time periods (2026 to 2035, 2056 to 2065, and 2086 to 2095) and two different climate change representative concentration pathways (RCPs): RCP 4.5 and RCP 8.5. Note: RCP 4.5 is the lower-emission scenario, and RCP 8.5 is the higher-emission scenario.

Our preliminary analyses show that the annual crop AEC would decrease with the climate changes, converting into the annual crop-fallow transition AEC. The relatively stable grain-fallow AEC would be less affected by climate change than other dryland AECs (Table 1, Figure 3). The projected shift in AECs could significantly decrease cropping system diversification and intensification, reduce overall soil organic matter, and increase soil vulnerability to erosion processes.

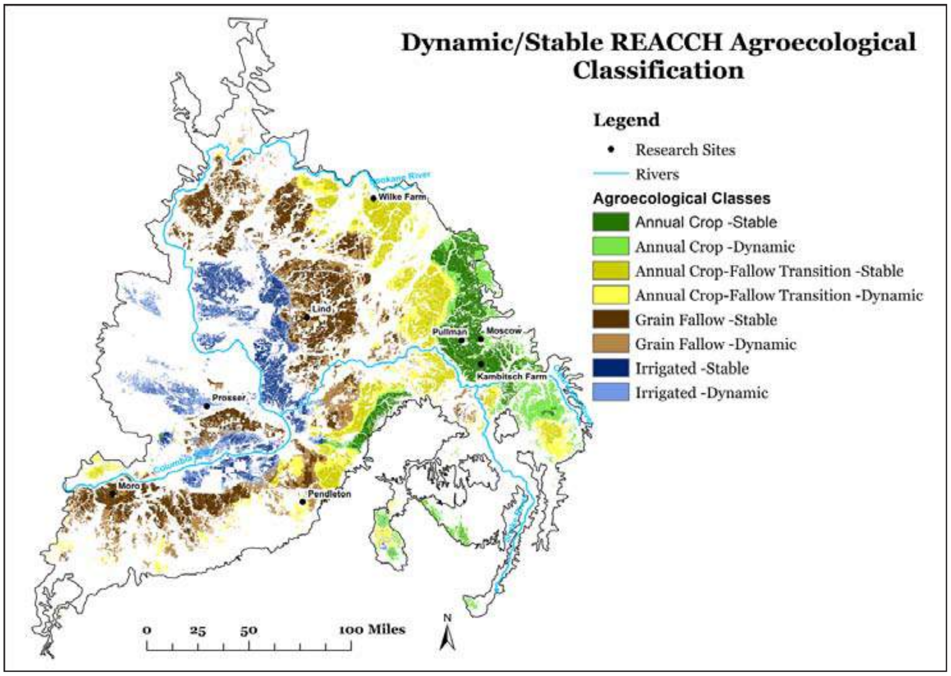


Figure 2. *REACCH agroecological classes for 2007 through 2013.*

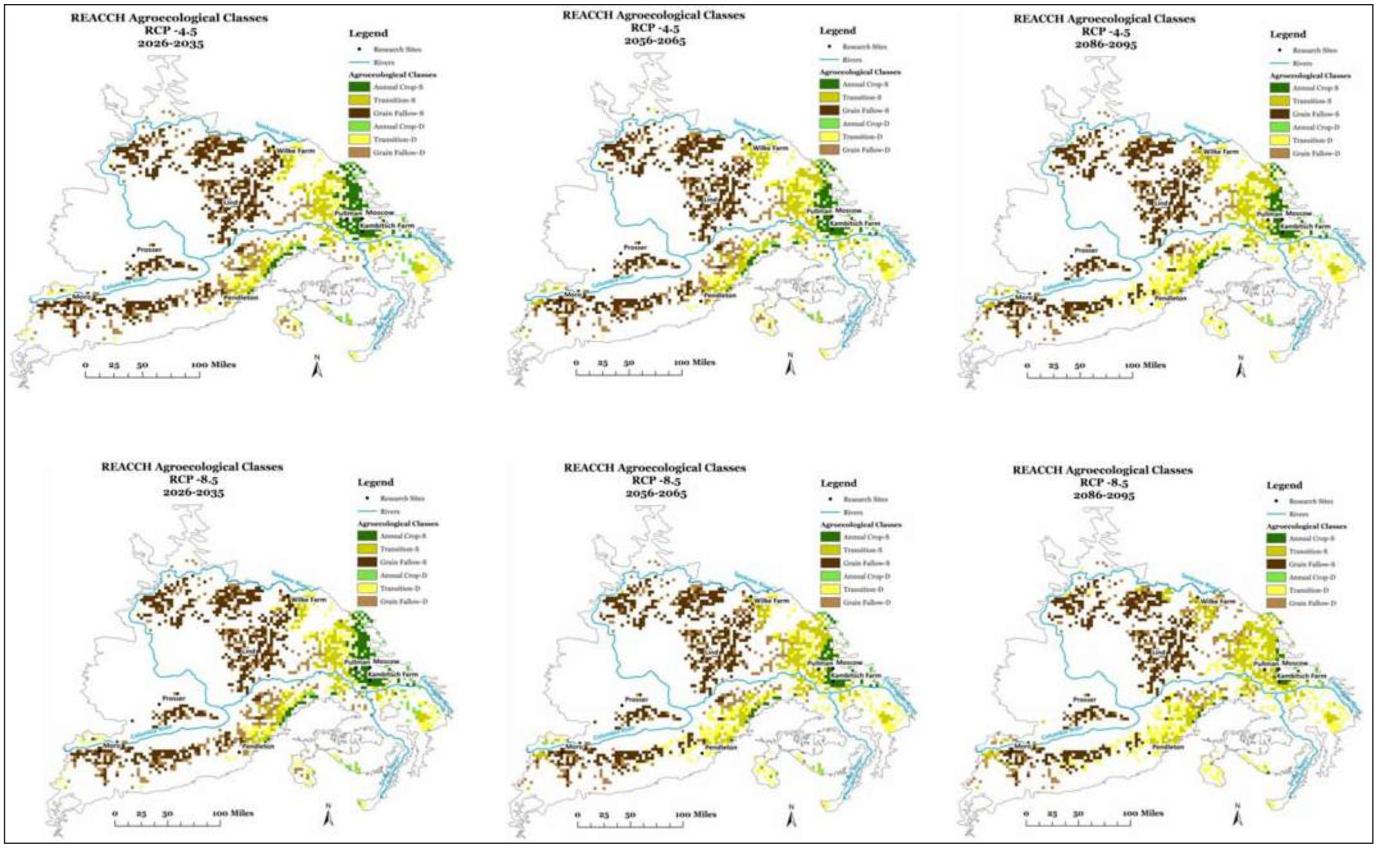


Figure 3. *Projected shifts in REACCH agroecological classes under different future scenarios.*

Is regional warming natural or not?

John Abatzoglou (jabatzoglou@uidaho.edu), Dave Rupp OSU, and Phil Mote OSU

Climate has changed substantially throughout Earth's history. However, the observed warming of 1.4°F since 1900 has spurred interest in identifying whether such changes are part of a natural cycle or due to human factors. The answer to this scientific question lies at the heart of whether our actions both have been responsible for documented changes and can be modified to ease the pace of warming and avoid subsequent impacts to global society.

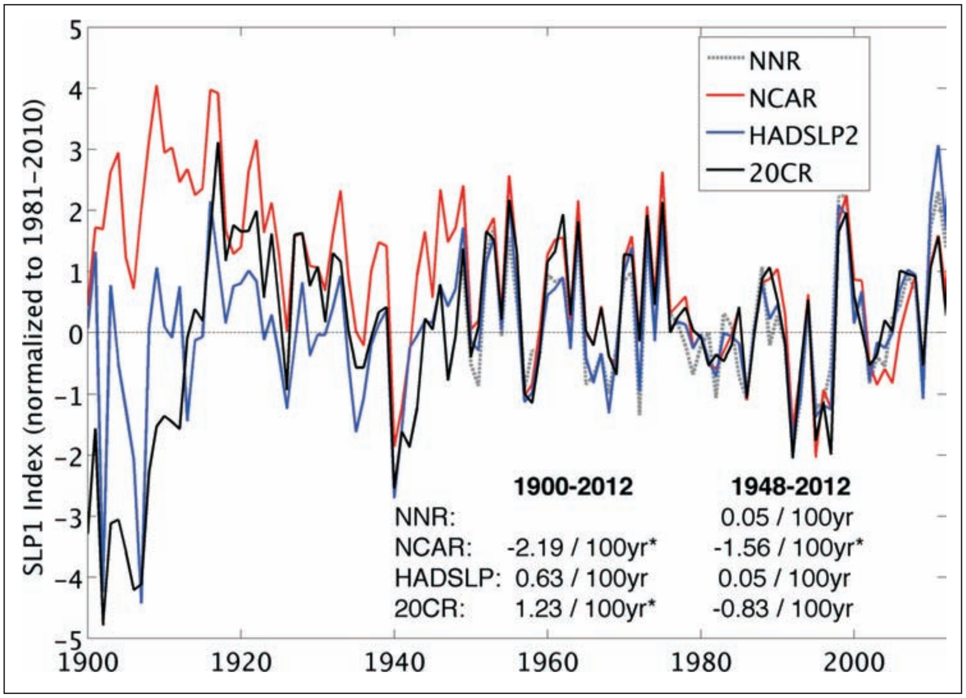
The increase in global averaged surface air temperature and sea surface temperatures over the past century has been well documented through a variety of means and has been estimated to be around 1.4°F from 1900 to 2012. This increase has not been a smooth upward glide, but rather has involved a sharp increase since the 1960s, with a widely reported slowing down (also known as the "hiatus") in surface-based warming since the record-setting El Niño year in 1998. While much has been made about this slowdown in warming, including speculations that the Earth system is not as sensitive to man-made forcing as reported, 2014 is the warmest year on record, which is remarkable given the lack of any significant El Niño event (El Niño years are generally warmer). Variations in global mean surface temperature arise primarily from three factors: (1) absorbed solar radiation, (2) strength of the atmospheric greenhouse effect, and (3) internal coupled ocean-atmosphere climate variability. The Intergovernmental Panel on Climate Change's fifth assessment report concluded that it is "extremely likely" that a majority of the increase in temperatures since the mid-20th century is due to man-made emissions of greenhouse gases and that modeled estimates of the man-made contributions were of similar magnitude to the observed warming.

IMPACT

Observed long-term warming of the Pacific Northwest has primarily been driven by man-made increases in greenhouse gas levels, despite recent reports to the contrary. The Pacific Northwest is thus not immune to human-driven changes in climate, historically and under future climate scenarios.

Regional variability in temperature is additionally subject to regional-to-hemispheric variations in atmospheric circulation. For example, the well-documented and repeated El Niño Southern Oscillation (ENSO) and Pacific North American (PNA) modes of variability are two of the more influential circulation patterns for much of the Pacific Northwest (PNW). While a portion of the year-to-year, decade-to-decade, and multidecadal variability in temperature can be linked to variability in these natural patterns, there is no long-term trend in these patterns that can explain the magnitude of observed 1.4°F warming in the region since 1900. Rather, in a 2014 study published in the *Journal of Climate*, we determined that accumulation of man-made greenhouse gases was the leading cause of the observed warming.

Recently, a study published in the *Proceedings of the National Academies of Science* by Johnstone and Mantua (JM) reported findings contradictory to ours, suggesting that natural changes in atmospheric circulation explain nearly all of the observed warming in WA, OR, and northern CA. They hypothesize that a long-term decline in air pressure over the northeastern Pacific Ocean has allowed for a more southerly flow and intrusion of warmer maritime air into the region.



	1900-2012	1948-2012
NNR:		0.05 / 100yr
NCAR:	-2.19 / 100yr*	-1.56 / 100yr*
HADSLP:	0.63 / 100yr	0.05 / 100yr
20CR:	1.23 / 100yr*	-0.83 / 100yr

Figure 1. *Time series of the annual mean of monthly sea-level pressure variability described by Johnstone and Mantua (JM) from four different datasets. Note that the National Center for Atmospheric Research (NCAR) dataset used by JM to reach their conclusions shows a significant decline over the period of record relative to the other datasets. Linear trends for the different datasets are provided and statistical significance is denoted by *. (NNR: National Centers for Environmental Prediction/NCAR Reanalysis; HADSLP: Hadley Centre Sea Level Pressure dataset; 20CR: National Oceanic and Atmospheric Administration 20th Century Reanalysis)*

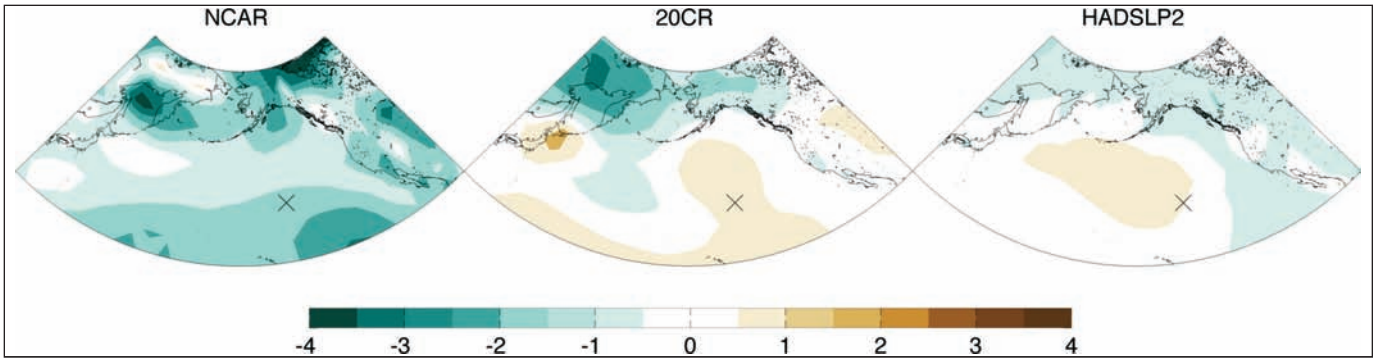


Figure 2. *Estimated linear least squares trends in annual mean sea-level pressure from 1900 to 2012 for three datasets: (left to right) National Center for Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration 20th Century Reanalysis (20CR), and Hadley Centre Sea Level Pressure (HADSLP2). Trends are reported in units of millibars per century. For reference, an × is placed over the center of action of the mode of variability reported by Johnson and Mantua.*

The authors based their conclusions on the long-term decline in air pressure from a single dataset extending back to the beginning of the 20th century (Figure 1). However, we found that other long-term estimates of sea-level pressure over the northeastern Pacific fail to replicate the results of the dataset they chose. Moreover, the dataset JM used shows a coherent, long-term decline over nearly the entire Pacific sector that suggests a systematic problem with trends for these data over the 1900 to 2012 period (Figure 2). Since surface winds are driven by relative, rather than absolute, changes in atmospheric pressure, it is doubtful that the broader changes reflected in these data would lead to dynamic changes in the wind and movement of warmer air into the region. Curiously, even for the more recent time period from 1948 to 2012, when long-term sea-level pressure estimates show broader agreement and more sophisticated atmospheric reanalyses are available, the data used by JM show a continual decline across the northeastern Pacific. Given that JM's findings are strongly predicated on the long-term decline in sea-level pressure, we suggest that their conclusions may be premature and are very sensitive to the choice of datasets. Whereas we have fairly strong agreement on temperature records for the region, there is much larger structural uncertainty regarding sea-level pressure estimates from the northeastern Pacific.

To reconcile our study with the novel circulation index (SLP1) identified by JM, we performed a multiple linear regression, as we did in our 2014 *Journal of Climate* study, that equally considered influences from (1) solar variability, (2) volcanic aerosols, (3) man-made greenhouse enhancements, and (4) natural circulation patterns. The latter included ENSO, PNA, and SLP1. We used the monthly average SLP1 averaged over three independent datasets, given the disparity in SLP1 trends. The modified analysis failed to change our fundamental conclusions (Figure 3). We maintain that man-made accumulations of greenhouse gases were the leading driver of long-term changes in seasonal temperature for the PNW. The inclusion of SLP1 resulted in slightly more interannual variability in spring and winter temperatures but was not linked to summer or autumn temperatures in any notable way, thus being far less important than ENSO or PNA for regional temperature.

We are not aware of any process that would allow human-driven warming in the PNW to vary substantially from human-driven warming in similar latitudes; this is fairly well simulated by climate model experiments. Furthermore, we find that decadal variability in regional temperature is very strongly correlated to global mean temperature, including most of the warming since 1960, whereas the mechanism described by JM would result in most of the warming prior to 1940. While natural climate variability has a demonstrated impact on modifying the pace of warming in the region, we believe that it has played a far lesser role in the long-term warming of the region than man-made factors.

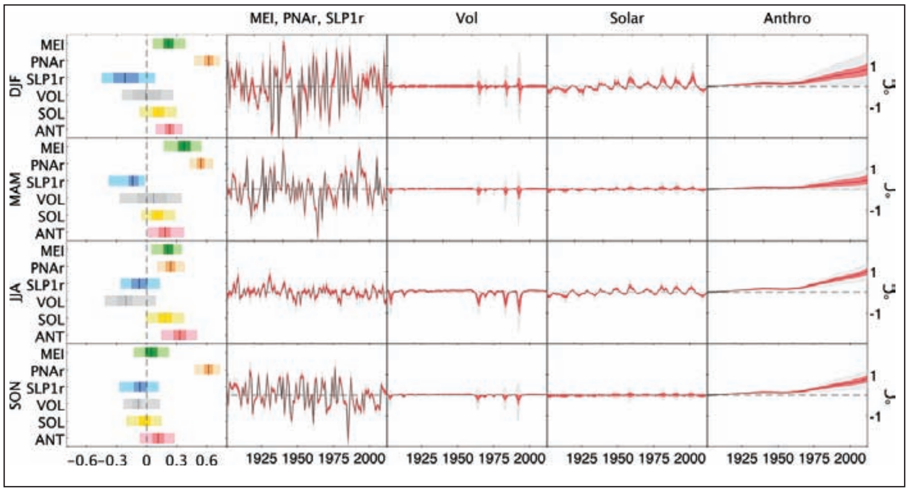


Figure 3. *(left column) Pearson's correlation coefficient between seasonal temperature and (1) Multivariate El Niño Southern Oscillation (ENSO) Index (MEI), (2) Pacific North American (PNA) index after removing the linear contribution (PNAr), (3) SLP1 index after removing the linear contribution from MEI and PNA (SLP1r), (4) volcanic aerosols (Vol), (5) solar variability (Sol), and (6) man-man factors (Ant). The box plots (right four columns) show the contribution to seasonal temperature due to (1) natural climate variability, (2) volcanic aerosols, (3) solar variability, and (4) man-made factors. The 95% confidence interval, interquartile range, and median of estimates are denoted by the light gray shading, red shading, and black line, respectively.*

REACCH
by the numbers

23.2 MILLION ACRES
3500 PRODUCERS

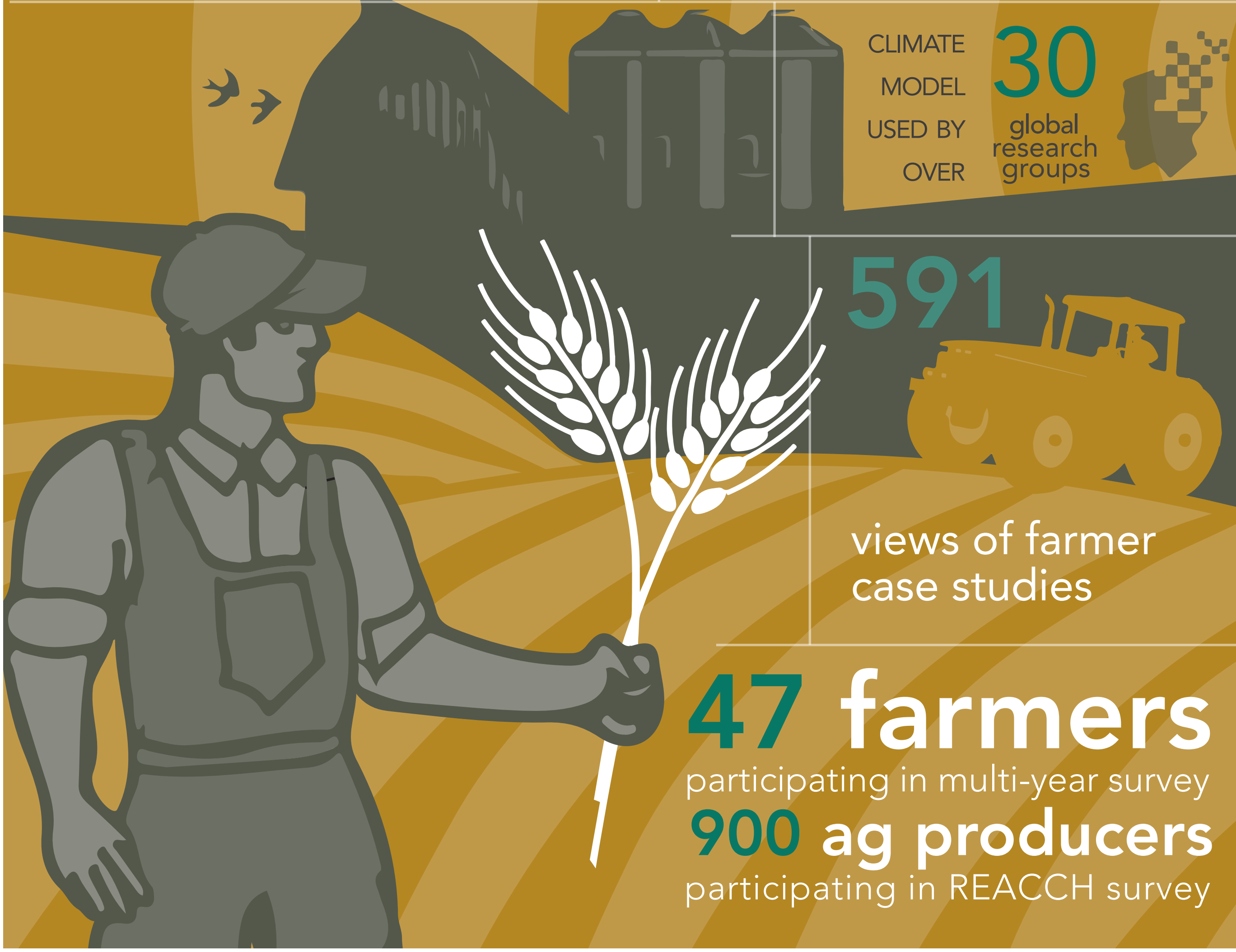
4500 STAKEHOLDERS PARTICIPATED IN REACCH EXTENSION ACTIVITIES IN YEAR 4

40% OF FARMERS incorporate winter canola into their wheat rotations

2274 hits on NITROGEN CYCLE WEBINAR

Over **1000** high school students using REACCH curriculum in **3** states

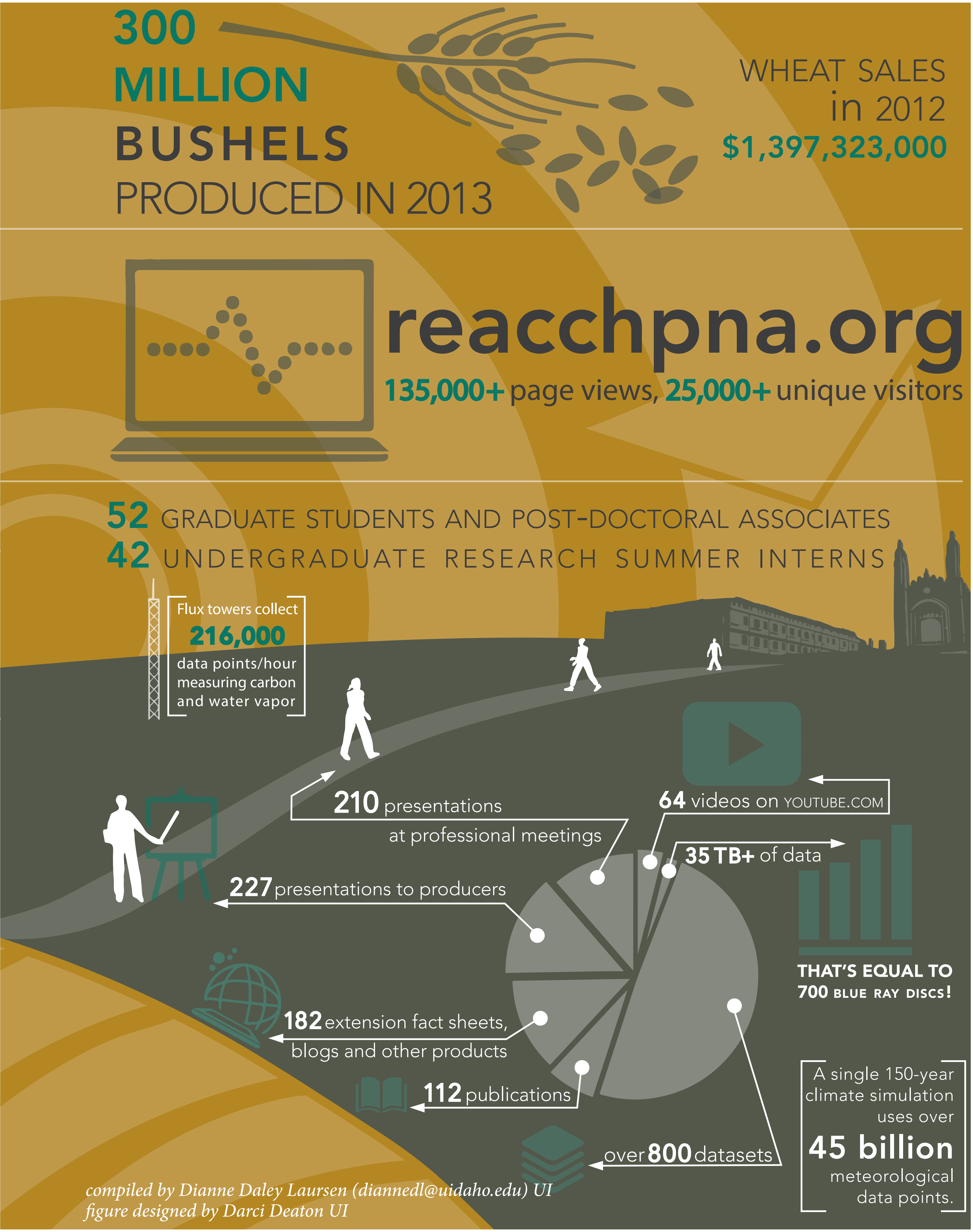
CLIMATE MODEL USED BY OVER **30** global research groups



591 views of farmer case studies

47 farmers participating in multi-year survey

900 ag producers participating in REACCH survey



300 MILLION BUSHELS PRODUCED IN 2013

WHEAT SALES in 2012 **$1,397,323,000**

reacchpna.org

135,000+ page views, **25,000+** unique visitors

52 GRADUATE STUDENTS AND POST-DOCTORAL ASSOCIATES

42 UNDERGRADUATE RESEARCH SUMMER INTERNS

Flux towers collect **216,000** data points/hour measuring carbon and water vapor

210 presentations at professional meetings

64 videos on YOUTUBE.COM

35 TB+ of data

THAT'S EQUAL TO 700 BLUE RAY DISCS!

227 presentations to producers

182 extension fact sheets, blogs and other products

112 publications

over **800** datasets

A single 150-year climate simulation uses over **45 billion** meteorological data points.

compiled by Dianne Daley Laursen (diannedl@uidaho.edu) UI
figure designed by Darci Deaton UI

Farmer-to-farmer case studies showcase resilient farms

Georgine Yorgey (yorgey@wsu.edu), Kristy Borrelli UI, Kate Painter UI, Hilary Davis UI, Sylvia Kantor WSU, Leigh Bernacchi UI, Chad Kruger WSU, and Dennis Roe WSU

Among the many excellent farmers in this region are some who are at the forefront of trying new farming practices. By adapting their tillage, residue management, crop rotations, soil organic amendments, and resource use efficiency, these farmers have been able to thrive when faced with risk. They have developed farming operations that achieve their economic and environmental goals within the constraints of their specific locations, as well as constraints that are universal to wheat-based farming throughout the region.

IMPACT

Case studies enrich farmer-to-farmer learning and provide all stakeholders with information about how farmers at the forefront of the industry are thinking about the future and dealing with risk. They can thereby enhance the resiliency of cereal-based farmers in the inland Pacific Northwest.

To help farmers and other stakeholders in the region learn from these innovative dryland and irrigated producers, we have featured these inland Pacific Northwest cereal farmers in a series of case studies. Four case studies (Figure 1), begun in 2013, will be published soon. Three new case studies are in progress, and three additional ones are planned for 2015.

The case studies aim to inspire other farmers and provide them with details that could inform their decisions regarding adoption of new strategies on their farms. Andy Juris, who farms with his father, Ron, in Bickleton, WA, summarizes this rationale well when he talks about how important information from other farmers has been to his operation:

> *When you talk about resources that have helped us transition to new practices, an equipment salesman or the results from a research experiment are always really nice. But when you hear a farmer say, "This is what we saw when we tried it," . . . or see the results or have a guy send you pictures and say, "Here's what it looks like," [it] is really worth a lot.*

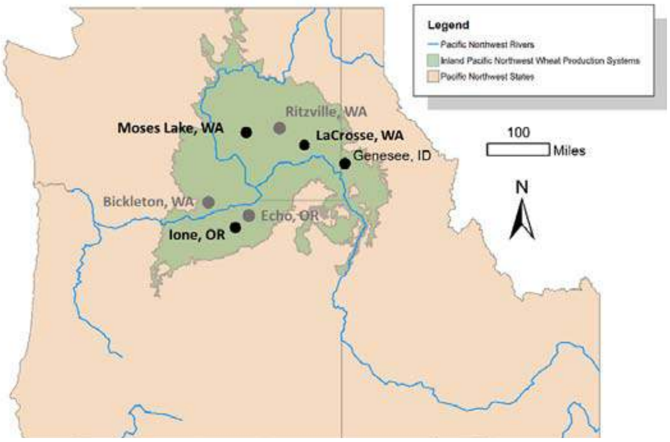


Figure 1. *Locations of 2013 case studies (black) and 2014 case studies (gray); additional case studies are planned for 2015. Map courtesy of Erich Seamon.*

We hope others working in the sector, including crop advisors, agricultural industry personnel, and researchers, will also find the case studies useful. Building an understanding of farm-level resilience can contribute to an understanding of adaptive capacity overall, and of what is needed to support ongoing adaptation to meet future challenges.

Final case studies include an extension publication and a short video. As they become available, materials will be posted at www.casestudies.reacchpna.org. The first four case studies—of Eric Odberg, Dale Gies, Steve and Becky Camp, and Bill Jepsen—are summarized below.

Mustard cover cropping
Dale Gies, Moses Lake, WA
Dale Gies has developed an intensive irrigated rotation of wheat, followed by mustard cover crop in the first year and potatoes in the second year. Despite its intensity, this rotation successfully suppresses soilborne diseases and nematodes, allowing him to intensify his rotation and cut fumigation costs while improving soil health. Dale also grows vegetable and cover crop seed crops, and consults with farmers around the world about improving disease control through rotations and cover cropping. Photo by Sylvia Kantor.

"We're able to produce good yields, good quality, and improve the soil while we're doing it."

Enhancing crop diversity

Steve and Becky Camp, LaCrosse, WA

Steve and Becky Camp are growing oilseeds and peas in an area that traditionally grows just winter wheat, spring wheat, and spring barley. They also make their own biodiesel from camelina. Steve and Becky's experimentation is guided by holistic management, with goals of building soil quality and reducing long-term risk. Photo by Sylvia Kantor.

"If each of those rotations has a direct advantage to the soil health, then I'm going to leave this farm in much better shape."

Flex cropping

Bill Jepsen, Ione, OR

Farmers in the part of northeastern OR where Bill Jepsen farms traditionally use a winter wheat–summer fallow rotation to cope with dry conditions and shallow soils. Bill has developed a flex cropping system that lets him replace fallow with a crop when moisture allows. Photo by Sylvia Kantor.

"Our goal is to make the most amount of profit, over the long haul . . . and the flexible rotation allows us to sneak in an annual crop when we would have nothing growing. . . . At the same time, we can control weeds and . . . improve our soils."

Precision nitrogen application

Eric Odberg, Genesee, ID

Eric Odberg was an early adopter of variable-rate nitrogen application in the annual dryland production region of the Pacific Northwest. Eric sees variable-rate applications as just one strategy in his ongoing efforts to keep his operation profitable and provide good stewardship for his land. Photo by Guy Swanson.

"It's a win as far as cost savings for me as a producer. And it's a win for the planet and general populace of less nitrogen going into our environment, whether it's in the atmosphere or our waterways."

Public perceptions of climate change and Pacific Northwest agriculture

Leigh Bernacchi (lbernacchi@uidaho.edu) UI, J. D. Wulfhorst UI, Liza Nirelli McNamee UI, and Monica Reyna UI

Debate over whether climate change is real and what can be done about it continues. Although it is not the main issue that the U.S. and European publics vote on, and many people struggle with how to discuss the key issues, the topic of climate change incites lively exchanges among scientists, politicians, and citizens. This short paper explores the perceptions of climate change among the general public in the Pacific Northwest (PNW). By surveying residents in this region, we established baseline information on the perceptions of climate change—with an emphasis on agriculture.

IMPACT

Public perceptions inform how we can address climate change in ID, OR, and WA. The general public is interested in seeing more action to address climate change through legislation at both the state and federal levels, via the agricultural community, and through individual choices. This creates an opportunity to promote the value of agriculture to address and mitigate food security risks related to climate change.

We designed the public perceptions survey within the context of agriculture to expand the integrative potential of REACCH: climate change can often be communicated through alternative topics that serve as "pivots" from a heated and divisive topic to a familiar one. In the 2013 REACCH annual report, we discussed how producers may pivot from focusing on long-term climate to discussing current water availability. For the public, food quality, the environmental impacts of agricultural production, and food security are seemingly hot topics—and a constructive alternative to pivot climate change into a more familiar and tangible context, such as the dinner table, feeding our families and questions like "where does our community get its food?" Additionally, our stakeholders need to be aware of public perceptions and attitudes toward climate change response and responsibilities in order to reflect their perspectives through policy.

How did we do it? We conducted a dual-frame (landline and wireless) telephone survey of the general public using a random sample stratified by rural and urban counties in ID, OR, and WA, yielding 1,298 responses (25% response rate, 43% cooperation rate). Data were adjusted for sample design and then calibrated in each stratum so that our sample was representative of the general population (e.g., gender and age). This research can help us understand the baseline of climate perceptions in the region and could inform institutional adaptations.

Global temperature and causes of climate change

Climate change is one of the most politically polarized topics today. Those surveyed responded to one of the key measures of climate change: a change in average global temperatures. We asked, "Based on your understanding of the earth's climate, how has the climate changed over the past 100 years?" with respect to temperature increase or decrease. Examining perceived change in temperature by political view (using a spectrum from conservative to liberal, rather than political party), we can see that across political views, a majority of respondents indicated that temperatures have increased (Figure 1).

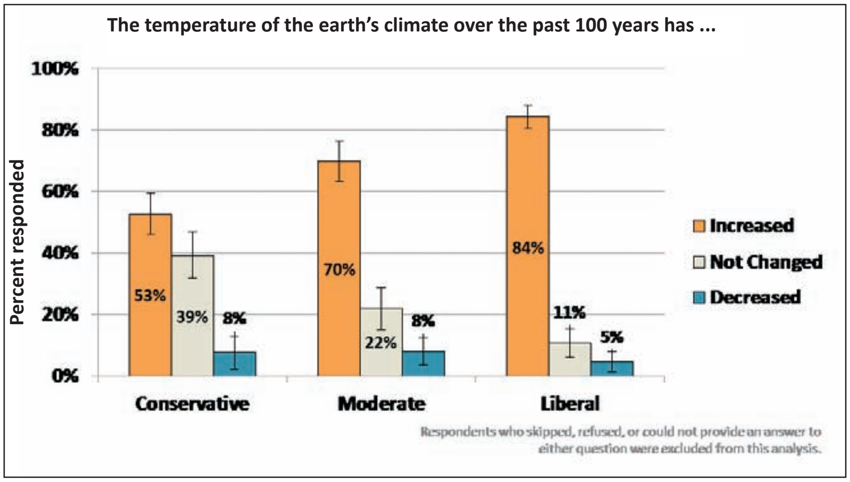
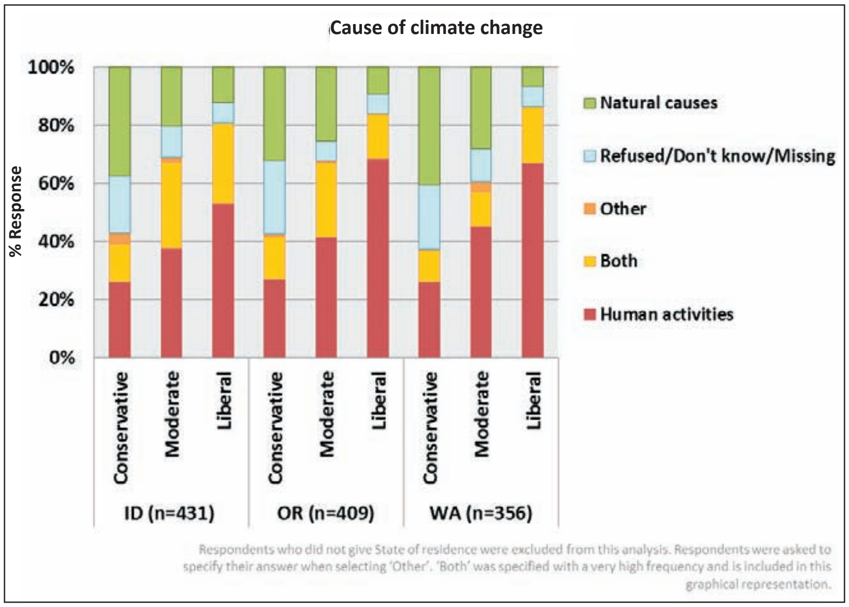


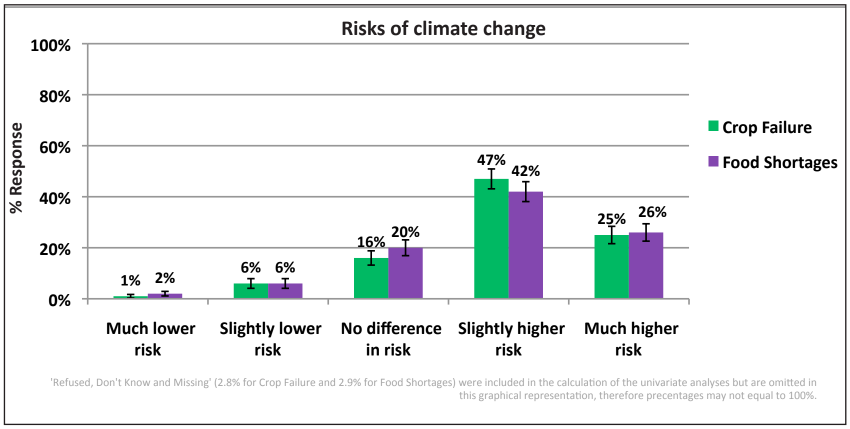
Figure 1. *Perceptions of temperature change over the past 100 years by political view. People who identified as liberal were more likely to say the earth's temperature has increased over the past 100 years. While the majority of conservatives agreed, a large portion (39%) said the temperature has not changed.*

The most intense aspect of climate change discussions is often the question of belief in climate change. Do you believe it is human caused? Naturally caused? Both? We asked, "What do you think is the main cause of this change in temperature?" Our respondents could reply "natural causes," "human activities," or "other." We coded qualitative responses of "other," including 17.7% of total respondents who specified that both humans and nature cause changes in temperature. Additionally, 14.2% of respondents either refused to answer, indicated "don't know," or asked to skip the question, revealing that a substantive portion of the population could be considered less "climate aware." Using a nominal



Respondents who did not give State of residence were excluded from this analysis. Respondents were asked to specify their answer when selecting 'Other'. 'Both' was specified with a very high frequency and is included in this graphical representation.

Figure 2. *Perceived cause of change in temperature by state and political view. While perceptions of the main cause of change in temperature (proxy for climate change) tended to be similar among the states, respondents with different political views answered the question differently: liberals, compared to conservatives, had 9.9 times higher odds of responding "human activities" than "natural causes."*



'Refused, Don't Know and Missing' (2.8% for Crop Failure and 2.9% for Food Shortages) were included in the calculation of the univariate analyses but are omitted in this graphical representation, therefore precentages may not equal to 100%.

Figure 3. *Perceived risks of climate change to regional agricultural resources. The majority of respondents said that an increase in risk of crop failure and food shortages due to climate change effects in the next 30 years is likely. Few people think there is a lower risk of these elements of food insecurity.*

logistic regression procedure, we addressed the relationship between the main cause of temperature change and political view, analyzed by state. Specifically, those who identified themselves as liberal (compared to conservative) had 9 to 10 times higher odds of responding "human activities" compared to "natural causes" as the reason for the change in temperature (Figure 2).

Risks of climate change

Respondents indicated that global temperatures are rising, with many noting humans as the cause, at least in part. Some climate change effects are often perceived as risks. With attention to how the PNW region and food security could be affected by climate change, we asked about risks to local food production, in terms of crop failures, and to food availability, in terms of shortages. Most respondents described at least slightly higher, if not much higher, risk of both food shortages and crop failures (Figure 3).

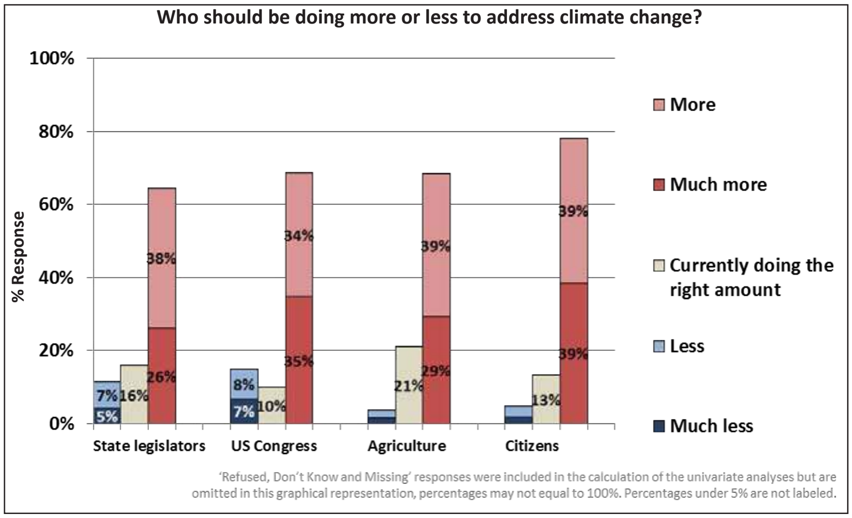
Response to climate change

Another reason that climate change remains such a current topic pertains to unresolved debate about who is responsible for adapting to or mitigating climate change. A telephone survey format does not lend itself to in-depth questions, but we asked respondents whether governing bodies, the agricultural community, and/or citizens "should be doing more or less to address climate change." The majority of respondents thought that all of these groups should be doing more to address climate change (Figure 4).

Our data indicate that, regardless of the percentage of respondents who think that climate change is primarily caused by humans (42%), the general public is interested in seeing more action to address climate change through legislation at both the state and federal levels, via the agricultural community, and through individual choices. This creates an opportunity to discuss the value of and opportunity for agriculture to address and mitigate food security risks related to climate change—a rhetorical pivot for climate change discourse in the PNW.

With this research we hope to add to the baseline of information about the public's perspective on climate change.

All analyses were conducted in SAS 9.3 (release date 2009). SAS Survey Procedures were used to account for survey design.



'Refused, Don't Know and Missing' responses were included in the calculation of the univariate analyses but are omitted in this graphical representation, percentages may not equal to 100%. Percentages under 5% are not labeled.

Figure 4. *Who should be doing more or less to address climate change? Respondents cited citizens as those who need to be doing more, above all other groups, but in general the majority of respondents think we should be doing more to address climate change. Fewer than 20% think we should be doing less.*

Measuring producer trust and attitudes about climate change

J. D. Wulfhorst (jd@uidaho.edu) UI, Leigh A. Bernacchi UI, Bob Mahler UI, Liza Nirelli McNamee UI, Monica Reyna, UI, and Susie Irizarry UI

How do producers learn about climate change? If we know what sources of information about climate change they trust and how they perceive climate change, we can more effectively reach out to these central stakeholders.

From November 2012 to March 2013, REACCH and the Social Science Research Unit (SSRU) of the University of Idaho (UI) administered a mail survey to agricultural producers in the REACCH region counties in the inland Pacific Northwest. The National Agricultural Statistics Service (NASS) provided a county-level sample of 2,000 producers who each grew more than 50 acres of wheat in 2011. The survey included perceptions of climate change, management practices, and demographics, as well as maps on which to mark parcels farmed. We received 900 completed and eligible surveys, 4 undeliverable surveys, and 38 ineligible recipients, resulting in an overall response rate of 45%. We followed all standard statistical and ethical practices.

IMPACT

Successful adaptation to climate change has social and community components related to producers' levels of trust in information from various sources. What you know is often a function of who you know and trust. We surveyed producers to see who they trust and what they know about climate change in order to better communicate our research with their trusted sources.

A variety of sources provide information about climate change. Farmers were asked about their levels of trust in general information as well as climate change information provided by the following sources (see Figure 1): (1) other producers in their county (Prod. in Co.), (2) crop advisors associated with a particular company (Co. CA), (3) university extension (U. Ext.), (4) local Soil and Water Conservation Districts (SWCD), and (5) state-level Natural Resources Conservation Service (NRCS). With respect to general information, relatively high levels of trust exist for other producers in the county, company-based crop advisors, and university extension personnel, with lower levels for SWCD and NRCS personnel.

From previous analyses, we know that the majority of producers either strongly agree or somewhat agree that they have observed changes in weather patterns over their lifetime. However, we also wanted to understand whether the dominant pattern of observing changes in weather has a relationship to trust. As shown in Figure 1, producers have the highest level of trust in general information from other producers in the county, yet their level of trust in climate change information from other producers is substantively lower. As such, we cross-tabulated producers' level of agreement with the statement "I have observed changes in weather patterns over my lifetime" with their level of trust in other producers from the county (Figure 2). Of those who agree with the statement about observed change in weather, 85% indicated trust in other producers, while 6% who disagreed with the statement indicated trust in other producers. This result reveals a strong correlation between trust in other producers and the

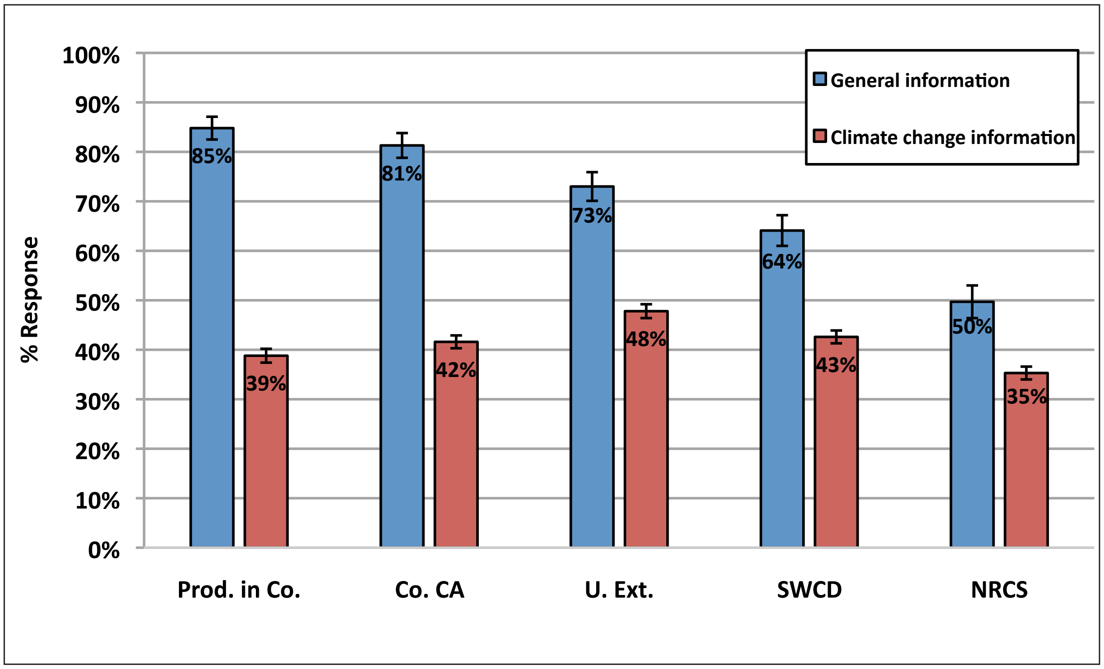


Figure 1. *How trustworthy do you find general information vs. climate change information from Producers in your country (Prod. in Co.), crop advisors from a particular company (Co. C.A.), University Extension (U. Ext.), Soil and Water Conservation Districts (SWCD) and Natural Resource Conservation Service (NRCS).*

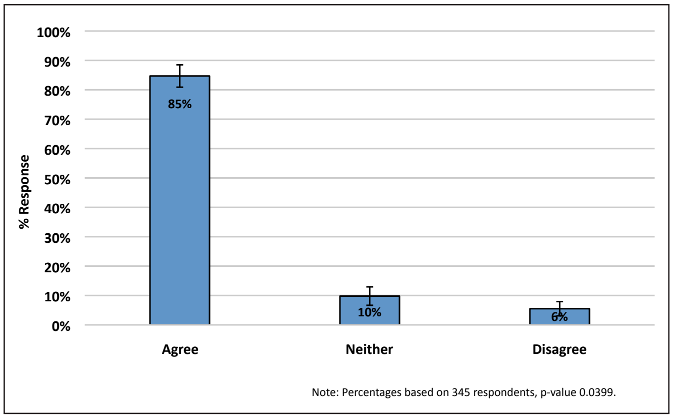


Figure 2. *Percentage who trust climate change information from other producers in county by level of agreement with the statement "I have observed changes in weather patterns over my lifetime."*

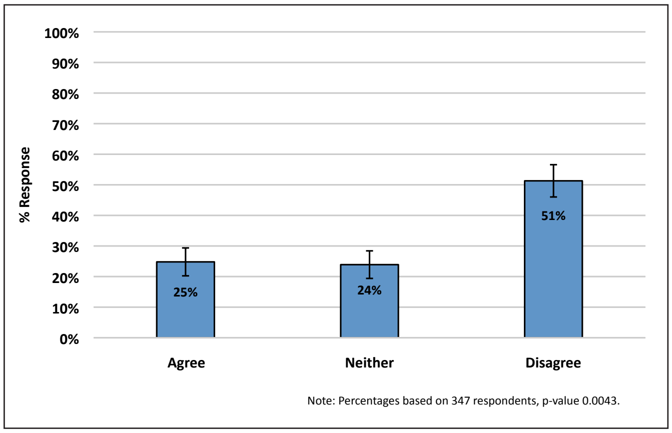


Figure 3. *Percentage who trust climate change information from other producers in county by level of agreement with the statement (collapsed) "Human activities are the primary cause of climate change."*

observation of weather change.

Similarly, we cross-tabulated the level of trust in other producers from the county with another statement about whether human activities are the primary cause of climate change (Figure 3). The results of this analysis revealed a different pattern, with only 25% of those who agree that climate change is human caused also indicating trust in other local producers and over half (51%) of those who disagreed that climate change is primarily human caused indicating distrust for other local producers.

The results of these base analyses indicate the need for further and more complex study of the role of trust in processing climate change information and adaptive behavior within the producer community. Insofar as producers trust each other the most about general information, an opportunity exists for direct community-based interactions to affect local behaviors in the most effective contexts. However, different dimensions of beliefs about climate change (e.g., whether it is occurring, its root causes, etc.) appear to suggest the need for a broader network of interactions between different sources of expertise and input.

Wheat field 5 miles south of Uniontown, WA on July 14th, 2014. Photo by Brad Stokes.

REACCH producers make the Internet a functional tool

J. D. Wulfhorst (jd@uidaho.edu) UI, Leigh Bernacchi UI, Bob Mahler UI, Liza Nirelli McNamee UI, Monica Reyna UI, and Susie Irizarry UI

A 41-question survey was distributed to producers in northern ID, eastern WA, and northeastern OR in 2012 with the purpose of studying how cultural, social, economic, and climatic factors affect decisions made on farms in the region. Our analysis of the results describes how farmers in the REACCH project use the Internet to support farming operations.

IMPACT

Beneficial use of the Internet has continued to expand among producers and could facilitate techniques for adapting to and mitigating climate change.

Most farmers in eastern WA, northern ID, and northeastern OR are using the Internet for at least some activities (Figure 1). Over 88% of the producers surveyed routinely visit websites on the Internet, while almost 82% commonly use the Internet to send e-mail for business. These numbers are similar to those observed for urban residents of the western United States. A majority of REACCH producers surveyed also use the Internet to help manage their finances (57%) and to share photographs (50%). Over one-third use the Internet to obtain, use, or share agriculture-related software.

Most REACCH producers use the Internet to find farm-related information (Figure 2). In fact, 64% of surveyed producers use the Internet for farm-related information on an everyday basis. Another 17%, 5%, and 3% of producers use the Internet once or twice a week, a few times a month, or a few times a year, respectively. In other words, we can estimate that 89% of producers use the Internet to search for and identify information that can be used to improve their farming operations.

The high percentage of the region's producers who are using the Internet indicates that the Internet can serve as a valuable tool for educating the agricultural community on improving the sustainability of agricultural systems. The land-grant universities in the region should take advantage of this outlet to disseminate timely agricultural information and research results.

Over one-quarter (26%) of surveyed producers in the REACCH study area currently use Internet-based mobile applications (apps) to support their farming enterprise (Figure 3). Another 12% have a mobile device but do not currently use apps to support farming operations. Over half of the producers surveyed do not currently use mobile apps.

Sixty eight percent of longitudinal survey respondents have access to the internet with their cell phone. Photo by Hilary Davis.

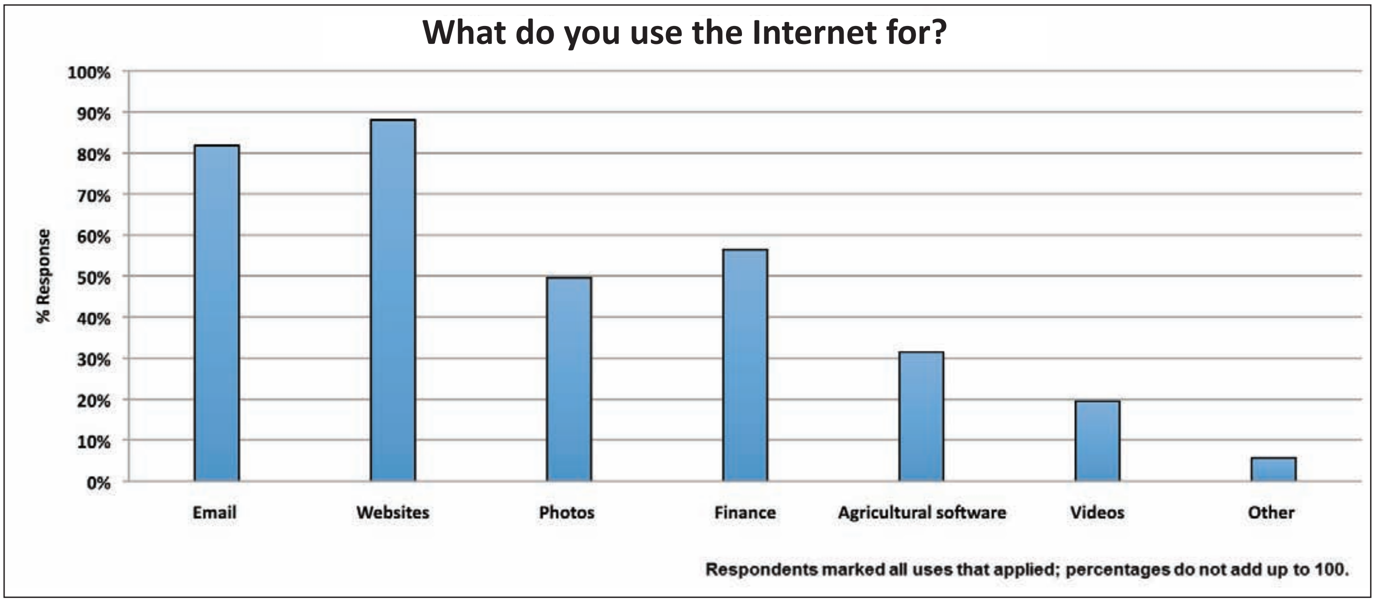


Figure 1. *Use of the Internet by producers for different activities in the REACCH project area.*

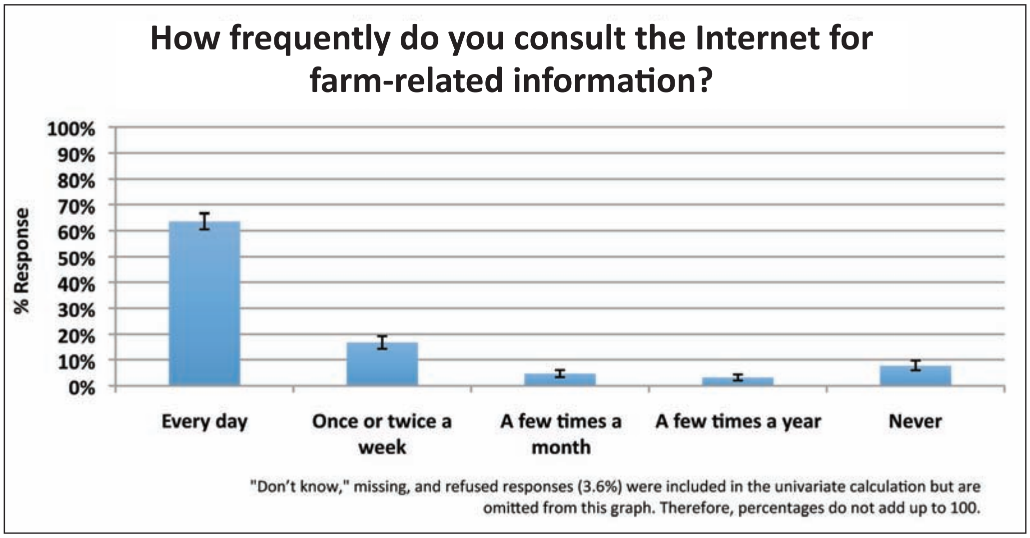


Figure 2. *Frequency with which producers in the REACCH project area consult the Internet for farm-related information.*

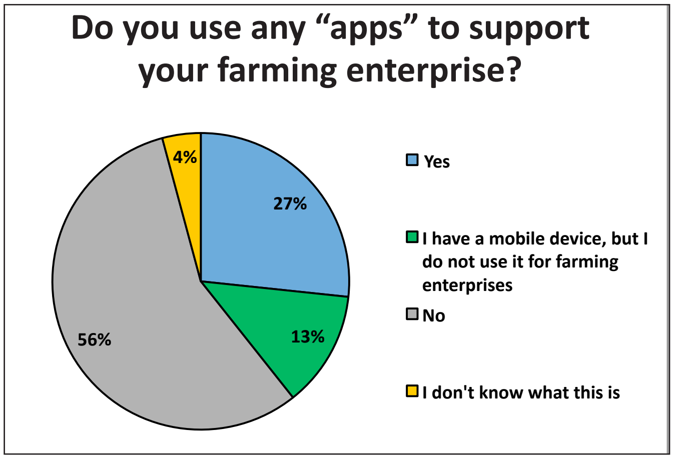


Figure 3. *Use of mobile apps to support farming enterprise by producers in the REACCH project area.*

The importance of soil fertility in crop production

Bob Mahler (bmahler@uidaho.edu) UI, Bill Pan WSU, and Don Wysocki OSU

IMPACT

Survey results demonstrate that growers in the REACCH region consider soil fertility to be an important component of sustainable cropping systems. They not only consider fertility important but also use key best management practices to enhance nutrient management.

Effective management of nutrients in soils is needed to feed the 7.3 billion people on the planet. Soil sampling and the use of nutrient application rates based on scientific principles and research are critical components of nutrient management. The purpose of this study is to document (1) the farmer-perceived value of soil fertility for crop yields, (2) the use of soil sampling for nutrient diagnosis, and (3) who actually makes fertilizer recommendations on cropland in the REACCH study area.

The data in this study were collected from a 2011 survey of 711 (53.2% response rate) growers in the REACCH study area. From the thirty three questions questions asked, this article will discuss the following four questions:

1. How important is soil fertility (nutrients) to your overall grain yields?
   a. Soil fertility is responsible for less than 20% of my yield
   b. Soil fertility is responsible for 20% to 30% of my yield
   c. Soil fertility is responsible for 30% to 40% of my yield
   d. Soil fertility is responsible for 40% to 50% of my yield
   e. Soil fertility is responsible for 50% to 60% of my yield
   f. Soil fertility is responsible for more than 60% of my yield

2. Do you take soil samples (for soil testing) to evaluate nutrient status of your soils prior to fertilization?
   a. Yes
   b. No
   c. Sometimes

3. If you answered yes to the above question, who takes the soil sample?
   a. You
   b. Fertilizer dealer
   c. Consultant
   d. County extension agent
   e. Other

4. Who makes your fertilizer recommendations?
   a. You
   b. Fertilizer dealer
   c. Consultant
   d. County extension agent
   e. Other

Mailing addresses of 1,337 active farmers were obtained from county extension agents in more than 20 counties in eastern WA, northern ID, and northeastern OR. The survey was distributed through the U.S. Postal Service, and the response rate exceeded 53%.

The majority of growers responding to this survey feel that soil fertility accounts for at least 50% of their crop yield (Table 1). This information is significant, because when coupled with recent research data, both researchers and growers feel that soil fertility is an important component of crop yield. The high percentage of yield attributed to soil fertility suggests that in the eye of the producer, soil fertility is at least as important to yield as crop variety selection and pest management, if not more important. Grower age, number of years farmed, and farm size do not affect the percentage of yield attributable to soil fertility; however, we observed a significant relationship between annual precipitation and yield attributed to soil fertility. In general, soil fertility is seen as an increasingly important component of yield as annual precipitation increases.

Table 1. *Relative importance of soil fertility to overall yields of dryland crops, based on a 2011 nutrient management survey in the REACCH study area.*

Percentage of yield attributable to soil fertility	Percentage of respondents
<20	2.0
20-30	7.4
30-40	8.5
40-50	19.6
50-60	27.7
>60	34.8

Over 68% of farmers in the REACCH study area regularly take soil samples, while 23.3% collect soil samples less often (Table 2). The respondents who take soil samples less often than once per year most likely collect them once during a crop rotation. This soil sampling likely occurs prior to planting the highest-income crop (wheat) in the rotation. Fewer than 10% of survey respondents do not have soil samples collected on their farms. The survey results indicate that more than 90% of the growers in the dryland farming areas of eastern WA, northern ID, and northeastern OR consider soil sampling important.

Even though the majority of survey respondents indicated that soil samples are regularly collected on their farms, most of the samples are not collected by the growers themselves. Fertilizer dealers, consultants, county extension agents, and other individuals take 62.8%, 4.6%, 0.6%, and 0.2% of the soil samples, respectively. Conversely, growers take 31.8% of the collected soil samples.

Photo by Brad Stokes.

Table 2. *Responses to the question "Do you take soil samples (for soil testing) to evaluate nutrient status of your soils prior to fertilization?" This information was collected as part of a nutrient management survey in the REACCH study area.*

Do you take a soil sample?	Percent of respondents
Yes	68.3
No	8.4
Sometimes	23.3

A majority of growers in the REACCH project area make fertilizer recommendations for their crops (Table 3). Fertilizer dealers are responsible for 36.7% of the fertilizer recommendations, while consultants (6.0%) and county extension agents (1.0%) provide fewer fertilizer recommendations. It is interesting to note that fertilizer dealers collect approximately two-thirds of the soil samples but provide only about one-third of the actual fertilizer recommendations. Farmers are willing to accept help with soil sampling but are more likely to make their own fertilizer recommendations.

The survey data show that most growers consider soil fertility a very important aspect of crop production. In addition, a majority of growers have an excellent grasp of the important nutrient management concepts involving the relationship between soil fertility and yield, soil sampling, and fertilizer recommendations. A large majority of growers place a high value on soil fertility. More than 62% of the surveyed growers attribute more than 50% of their annual crop yield to soil fertility. Conversely, fewer than 10% of the growers attribute less than 30% of their yield to fertility.

An important overall conclusion from this survey is that farmers are literate about soil fertility issues. It would be nice to attribute a significant part of this high literacy to successful soil fertility extension programs offered by the three land-grant universities in the region—Oregon State University, Washington State University, and the University of Idaho. However, factors other than extension education are probably part of this improved literacy. For example, economics likely plays a big role. Since 1981, the cost of nitrogen fertilizer has increased by more than 122%. This cost increase has resulted in nutrient management becoming a larger overall cost of cereal production. This cost has made growers take notice and be on top of all aspects of nutrient management in their crops. This development alone has probably resulted in better soil sampling and nutrient diagnostics, and consequently in improved fertilizer recommendations.

Table 3. *Responses to the question "Who makes your fertilizer recommendations?" This information was collected as part of a 2011 nutrient management survey in the REACCH study area.*

Who makes your fertilizer recommendations?	Percent of respondents
You	54.6
Fertilizer dealer	36.7
Consultant	6.0
County Extension agent	1.0
Other	1.7

Life cycle assessment of Pacific Northwest canola-based biodiesel

Chad Kruger (cekruger@wsu.edu) WSU, Claudio Stockle WSU, Dev Shrethsa UI, Kate Painter UI, and Bill Pan WSU

The production of canola and other brassica-based oilseeds has long been promoted as a strategy for diversifying cereal-based cropping systems in the inland Pacific Northwest (PNW). As can be observed in Figure 1, canola has great potential as a rotational crop for wheat production in the region. However, success has been limited by the lack of a viable regional processing infrastructure for crushing the seed. Recent policy-driven interests in renewable energy and carbon mitigation have contributed new resources and enthusiasm for production of oilseeds, in particular the strategy of regionally produced biofuels that can help meet a low carbon fuel standard (LCFS). The U.S. Environmental Protection Agency (EPA) has developed an estimated value for an LCFS for canola-based biodiesel based on midwestern production data, but many producers are concerned that the existing EPA estimate is not an adequate representation of production conditions in the PNW. The PNW enjoys a highly diverse landscape and climatic system with a variety of agroecological zones under which different cropping systems (crop type, varieties, agronomic management, etc.) have evolved. The consequence of this heterogeneity is that there is no single set of expected production inputs and outputs that is universally applicable across the region, and therefore a lifecycle assessment (LCA) for a crop produced in the PNW should account for the range of production issues in the region. The brassica oilseed crops (canola, mustard, and camelina) have an even greater degree of heterogeneity due to the fact that their commercial introduction to the PNW is recent and they do not have the same history of varietal and agronomic development as wheat. Our team used the CropSyst model to simulate yield, carbon sequestration, nitrous oxide emissions, carbon footprint, water dynamics, and land use impacts for canola production in the inland PNW as a basis for providing the EPA with a regionally appropriate estimate for the LCFS for canola-based biodiesel.

IMPACT

Canola has great potential as a rotational crop for wheat production in the inland Pacific Northwest. This study provides the first regionwide lifecycle assessment of the production of canola for use as a feedstock for biodiesel.

Tables 1 and 2 show the baseline and alternative rotations simulated in this study.

Highlighted findings from the simulation

- Crop rotations with canola differ considerably in their production inputs and potential yields across the inland PNW, indicating the need for a more detailed subregional analysis of the potential impacts of feedstock production in the region.
- Crop simulations do partially capture a “rotation effect” that supports the claim that shifting to canola production should not be treated as a 1:1 land substitution for current grain production. Our analysis indicates that the displaced food value ranges from -10% to -31%, depending on location and crop rotation.
- Because current crop simulations do not fully capture the “rotation effect” observed by farmers and reported in experiments, there may be additional, positive impacts on yield, input costs, land substitution, and other lifecycle factors that require further quantification.
- Estimated average yields across the PNW were the equivalent of 66 gallons of biodiesel per acre for spring canola and 71 gallons for winter canola, with substantial spatial and temporal variability.
- Simulated alternative crop rotations containing canola do not result in a significant change in soil carbon sequestration or nitrous oxide emission relative to current cropping systems. The net change in total production-related greenhouse gas emissions of the alternative canola rotation over the conventional rotation is also not significantly different.

Table 1. *Baseline crop rotations for each location.*

Location	Annual Precipitation (inches)	Crop rotation
Lind, WA	10.0	WW – SF
Moro, OR	11.5	WW – SF
Davenport, WA	14.1	WW – SW – SF
St. John, WA	17.2	WW – SW – SF
Moscow, ID	27.4	WW – SW – SW

WW = winter wheat; SW = spring wheat; SF = summer fallow.

Table 2. *Alternative crop rotations for each location.*

Location	Annual Precipitation (inches)	Crop rotation
Lind, WA	10.0	WW – SF – WC – SF
Moro, OR	11.5	WW – SF – WC – SF
Davenport, WA	14.1	WW – SW – SF – WC – SW – SF
St. John, WA	17.2	WW – SW – SF – WC – SW – SF
Moscow, ID	27.4	WW – SC – SW

WW = winter wheat; SW = spring wheat; WC = winter canola; SC = spring canola; SF = summer fallow

- Our analysis indicates that relative to petroleum diesel, use of canola feedstock in biodiesel production reduces lifecycle greenhouse gas emissions by 66% and 67%, respectively, for spring and winter canola.
- Canola biodiesel produces 3.4 and 3.5 units of energy per unit of energy spent during processing for spring canola and winter canola, respectively.

Summary and conclusions

Simulated crop rotations with canola were observed to have a small, generally positive impact on wheat yields. While the introduction of canola would displace some acreage of the dominant cereal grains produced in the region, the ultimate displacement effect on a mass food value basis ranged from losses of only 10% to 31%, depending on location and rotation in these simulations. This is much lower than the assumed 1:1 displacement on an acreage basis. Accounting for the observed "rotational effect" of disease and weed suppression not captured in model simulations may push this trade-off closer to a net-zero displacement effect. Therefore, land use displacement or "food for fuel" concerns should not be significant for PNW canola production.

Overall nitrous oxide emissions were slightly lower for the alternative canola rotation than for the conventional wheat rotation, but the difference is too small to be significant. Soil carbon sequestration of the alternative rotation ranged from 768 to - 887 pounds of carbon dioxide (CO_2) per acre (862 to -996 kilograms of carbon dioxide (CO_2) per hectare) annually and is also not significantly different from the conventional wheat rotation. As seen in conventional rotations from earlier studies, the generation of nitrous oxide generally outweighs the potential benefit of increased soil carbon sequestration. The net change in total production-related greenhouse gas emissions of the alternative canola rotation over the conventional rotation ranges from 45 to - 68 pounds of CO_2 per acre (50 to -76 kilograms of CO_2 per hectare) annually, but again is not significantly different.

From a crop production standpoint, the carbon footprint implications of shifting to alternative rotations that include canola relative to a conventional wheat rotation, while different depending on location and system, are small in comparison to the impacts of reducing tillage in wheat production systems, as indicated by earlier crop simulation studies. The potential agronomic and environmental benefits created by adding canola (or other oilseeds), especially when that addition facilitates adoption of no-till or reduced tillage, are likely far greater in significance than the carbon footprint implications of the canola rotations.

Figure 1. *Coauthor Bill Pan (left) assessing a field of canola. Photo by Karen Sowers.*

Soil carbon and nitrogen fractionation following biosolids applications

Lauren Young (leyoung@wsu.edu) WSU and Bill Pan WSU

Anaerobically digested and dewatered biosolids can be an effective source of nutrients in a cropping system, and application of biosolids from municipal solid waste facilities to farmland in WA has been practiced since the 1980s. In Douglas County, more than 50,000 acres of wheat-fallow agricultural land is part of the Boulder Park Project, where biosolids have been used as a crop nutrient source and to reduce soil erosion. Biosolids from wastewater treatment in WA's King County are trucked across the Cascade Mountains, spread on the soil, and incorporated within six hours of application. These biosolids supply a full complement of plant nutrients, which reduces the need for synthetic fertilizers that require fossil fuel inputs and generate greenhouse gas emissions, while also helping sequester carbon as soil organic matter.

IMPACT

The use of biosolids for plant nutrition benefits our agroecosystem by reducing emissions associated with synthetic fertilizer production and increasing soil carbon and nitrogen sequestration.

Intensive cropping practices in cereal production systems have led to degraded agricultural soils, largely characterized by a decrease in soil organic matter. Organic matter is a vital component of our soils; it lends itself to the better storage of nutrients and water in the soil and helps bind soil particles together so that they remain in place under conditions that could cause wind or water erosion. When organic matter in the soil declines, soils become more vulnerable to erosion. Long-term experiments have shown that the most effective way to rebuild soil organic matter while still harvesting a crop from the land is by applying organic soil amendments that are high in carbon.

Since 1994, researchers from Washington State University have been monitoring a cropping system in Douglas County where biosolids from a waste water plant in King County were applied for wheat production. The biosolids were applied every four years, in the fall following wheat harvest, at rates of 2.0, 3.0, or 4.5 dry tons per acre. These biosolid-amended systems were compared to one receiving no applications of biosolids and no nitrogen fertilizer, and to a system where no biosolids were applied but nitrogen was applied in the form of anhydrous ammonia (NH_3) every two years, in the spring of the fallow year.

Analysis of a time series of soil samples has shown that application of biosolids led to an increase in soil carbon and soil nitrogen. Different application rates yield different soil accumulation rates, as seen in the larger increase in soil carbon and nitrogen when 4.5 dry tons per acre were applied to a field, compared to the 2.0 dry tons per acre rate (Figure 1). What is most clear is that the application of biosolids at any of the three investigated rates led to an increase in soil carbon when compared to (1) a system that has had no nutrient additions and (2) one that has had only additions of conventional nitrogen fertilizer.

The increase in total soil carbon was more than 70% of what was applied as biosolids, while the increase in total soil nitrogen is about 35% of what was applied. One of the main reasons for this difference in accumulation rates is that grain, which is high in nitrogen, is harvested by the farmer and removed from the system, instead of contributing to the plant-soil nutrient balance.

Along with analyzing total carbon and nitrogen, we can separate different fractions to determine the form in which the nutrients are being stored. Acid hydrolysis is a procedure used to quantify the amount of carbon and nitrogen stored in a way that is resistant to digestion by a strong acid. To measure this, researchers reflux a 1-gram soil sample in hydrochloric acid at 240° F for 16 hours. After refluxing, the remaining soil is washed with pure water, and analyzed for total carbon and nitrogen content. The amount that remains allows us to calculate the acid-resistant

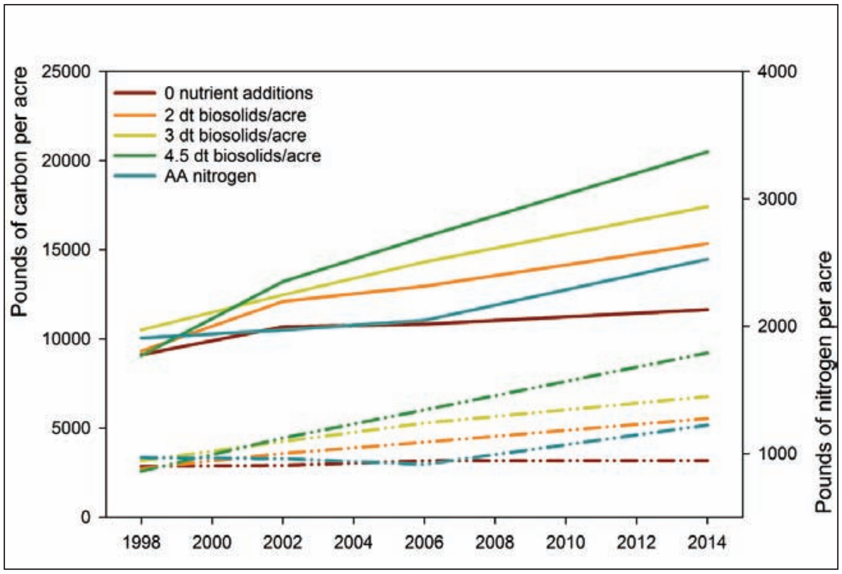


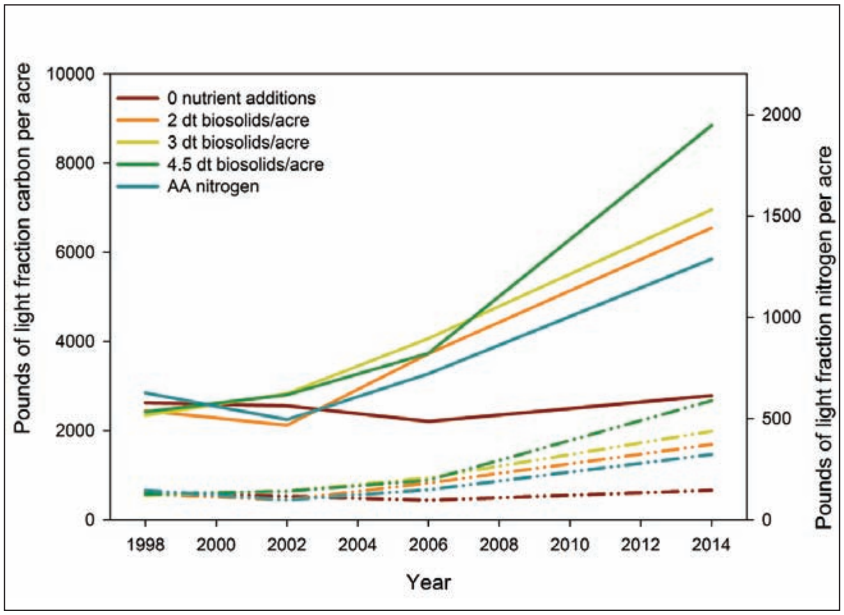
Figure 1. *Total carbon and total nitrogen measured in the soil. The dashed lines represent the nitrogen fraction, and the solid lines represent the carbon fraction.*

A winter wheat field, part of the Boulder Park biosolids project. Photo by Craig Cogger.

carbon and nitrogen fractions. The resistant fraction has been shown to be stable over time and does not change much with land management practices. The data from this site support that definition—the acid-resistant carbon fraction has increased over time, but very little, and the acid-resistant nitrogen fraction has not seen a significant change.

In contrast to the acid-resistant fraction, the light fraction is highly responsive to soil management. Light fraction carbon and nitrogen is measured by mixing a soil sample with sodium iodide (NaI), which has a density of 14 pounds per gallon. The light fraction floats on top of the NaI solution, while heavy soil particles sink to the bottom. The light fraction is then skimmed off of the NaI, treated to remove any remaining NaI, weighed, and analyzed for carbon and nitrogen content. The trends for light fraction carbon and nitrogen increases are very similar to what is seen in total carbon and nitrogen—the systems with additions of biosolids show major increases in the light fraction (Figure 2).

The light fraction exhibits the greatest increase in response to biosolid applications, and is the main contributor to the observed carbon and nitrogen sequestration. Biosolids are applied at a rate that provides optimum nutrition for growing wheat crops, and they have the added benefit of increasing soil organic matter to protect soil quality and sequester carbon and nitrogen. By reducing inputs of fossil fuel-intensive synthetic fertilizers, and acting as a carbon sink in our agroecosystem, biosolids applied to agricultural lands can help reduce carbon emissions associated with our farming systems.



Spreading biosolids on a wheat field in Douglas County, WA. Photo by Craig Cogger.

Figure 2. *Light fraction carbon and nitrogen as measured in the soil. The dashed lines represent the nitrogen fraction, and the solid lines represent the carbon fraction.*

Late-planted winter triticale in the dry region

William Schillinger (william.schillinger@wsu.edu) WSU, Ron Jirava (farmer collaborator), John Jacobsen WSU, and Steve Schofstoll WSU

IMPACT

Farmers and scientists have tried for decades to find a niche for no-till fallow as an alternative to tillage-based fallow in WA's dry wheat production zone. Our research has shown that late-planted (mid-October) winter triticale produces a grain yield equal to that of early-planted (first week of September) winter wheat. Early-planted winter triticale produces an average 18% greater grain yield compared to early-planted winter wheat.

Triticale is a cross of wheat and rye that is used as a feed grain. Although it has been produced on a small scale for several years, triticale has not been widely grown in eastern WA due to the historically low market price of feed grains compared to wheat. Feed grain prices have increased in recent years.

Beginning in the fall of 2010, winter triticale was incorporated into the long-term cropping systems experiment on the Ron Jirava farm near Ritzville, WA. We had discovered through previous experimentation that winter triticale does considerably better than winter wheat in late (mid-October or later) planting and thought that triticale might be a good fit for no-till summer fallow. Early planting into no-till fallow in late August to early September is generally not feasible in the low-precipitation zone due to a lack of seed-zone moisture. We planted winter triticale at the Jirava study into no-till fallow. Late-planted winter triticale goes into the winter months in the two- to three-leaf stage (Figure 1) but grows rapidly in the spring (Figure 2).

Heavy regionwide rain events exceeding 1 inch occurred during July or August of 2010, 2011, 2012, and 2013. Due to these abundant summer rains, there was adequate seed-zone soil moisture for early planting in no-till fallow. We therefore planted half of each triticale (variety 'Trimark 099') plot early (first week of September) and the other half late (mid-October). Winter wheat

Figure 1. *Late-planted winter triticale (left) goes through the winter months in the two- to three-leaf stage, whereas early-planted winter triticale (right) is much further developed. Photo was taken on March 14. However, unlike late-planted winter wheat, late-planted winter triticale grows quickly in the spring and produces ample grain and straw biomass (see Figure 2). Photo by Bill Schillinger.*

(variety 'Xerpha') was planted into tilled summer fallow during the first week of September on the same date as the early-planted winter triticale. Fertilizer and herbicide inputs were the same for all treatments. The seeding rate for early-planted winter triticale and winter wheat was 40 pounds per acre and for late-planted winter triticale was 60 pounds per acre.

Over the four crop years, the late-planted winter triticale grain yield averaged 3,798 pounds per acre and early-planted winter wheat 67 bushels (4,020 pounds per acre), these yields being statistically equal (Figure 3). Early-planted winter triticale grain yield averaged 4,901 pounds per acre, which significantly exceeded the average yield of early-planted winter wheat (Figure 3).

The price a grower would receive for triticale today (October 9, 2014) in Wilbur, WA, is $136 per ton versus $5.82 per bushel for soft white wheat. Therefore, the average 67 bushels of soft white wheat from our study is worth $390 per acre and the average early- and late-planted winter triticale is worth $333 and $258 per acre, respectively. In several recent years, growers could sell triticale for more than $200 per ton.

Our long-term research in the low-precipitation wheat-fallow zone of eastern WA has conclusively documented that late-planted winter wheat produces, on average, 36% less grain yield compared to early-planted winter wheat. Our research shows that late-planted winter triticale produces a yield equal to that of early-planted winter wheat. Additionally, early-planted winter triticale produces a significantly greater grain yield than winter wheat planted on the same date (Figure 3).

In addition to its high grain yield, winter triticale can be grown in the same manner and with the same inputs and equipment used for winter wheat. In-crop grass weed herbicides such as Maverick™ and Olympus™ can be used on triticale. Winter triticale grows taller and produces more residue than winter wheat (Figure 2), and thus it is a good choice for soils prone to wind erosion.

Figure 2. *Early-planted (right side) and late-planted (left side) winter triticale in early July near Ritzville, WA. Photo by Bill Schillinger.*

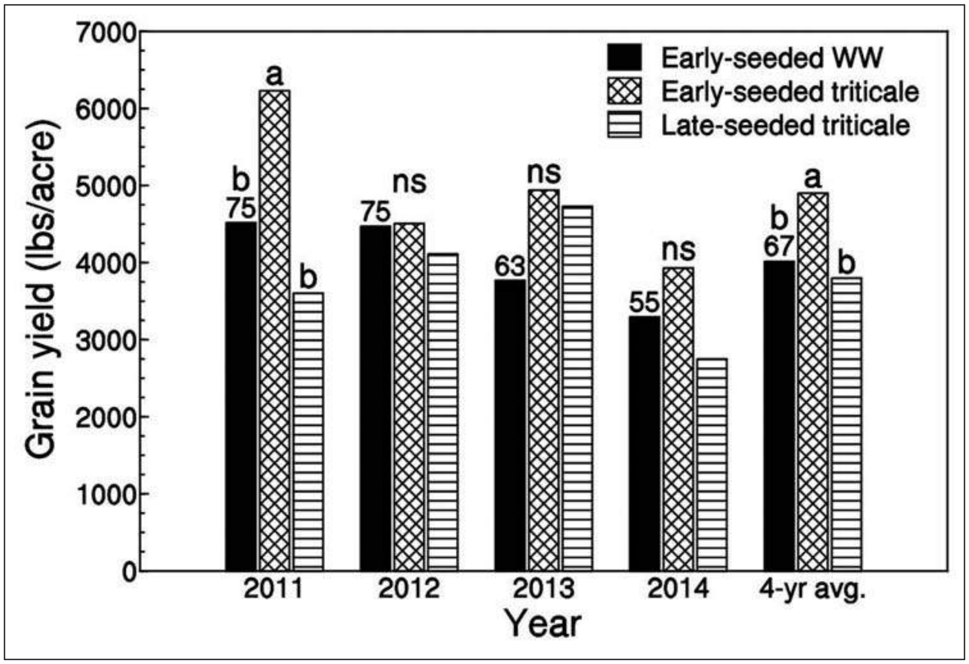


Figure 3. *Grain yield of both early- and late-planted 'TriMark 099' winter triticale planted into no-till summer fallow versus early-planted 'Xerpha' soft white winter wheat (WW) in a long-term cropping systems experiment near Ritzville, WA. Within-year grain yields followed by a different letter are significantly different at the 5% probability level. Numbers over the wheat yield bars indicate bushels per acre.*

Soil organic carbon dynamics in Pendleton long-term experiments

Rajan Ghimire (rajan.ghimire@oregonstate.edu) OSU and Stephen Machado OSU

IMPACT

The results from these long-term experiments (LTEs) clearly indicate that soil organic carbon (SOC) was depleted in winter wheat, summer fallow (WW-SF) systems. The loss of SOC has significant negative impacts on ecosystem services and the regional climate. Minimum soil disturbance, along with intensification and diversification in cropping systems, may improve SOC accrual and hence the sustainability of dryland cropping in the Pacific Northwest.

The dryland winter wheat (*Triticum aestivum* L.), summer fallow (WW-SF) system using conventional tillage (CT) in the Pacific Northwest has created a significant loss of soil organic carbon (SOC) in the last century and, in the process, added significant amounts of carbon dioxide (CO_2) to the atmosphere. The loss in SOC is attributed mainly to insufficient carbon inputs (one crop in two years) coupled with intensive tillage. The repeated intensive tillage aerates the soil and brings crop residues into contact with microbes, thereby enhancing SOC oxidation and loss.

In this study, we evaluated SOC in two long-term experiments (LTEs) established at Oregon State University's Columbia Basin Agricultural Research Center near Pendleton, OR. The crop residue LTE (CR-LTE) was established in 1931. It has nine treatments consisting of crop residue (fall burn, spring burn, and no burn) and fertility (0, 45, and 90 kilogram nitrogen per hectare per crop, manure, and pea vine) management practices under a WW-SF system. All plots were tilled using a moldboard plow, cultivated, and rod-weeded to control weeds. The wheat-pea long-term experiment (WP-LTE) was established in 1963. It has four treatments consisting of conventional tillage (fall plow and spring plow) and conservation tillage (minimum-till and no-till) systems under a wheat-pea rotation. We compared SOC levels in these two experiments to those in a nearby grassland pasture (GP) that has been maintained in native vegetation since 1931. The study site has a medium-textured soil (Walla Walla silt loam) and receives approximately 16.5 inches (420 mm) annual average precipitation. We took soil depth profiles at 0 to 10, 10 to 20, 20 to 30, and 30 to 60 centimeters (0 to 4, 4 to 8, 8 to 12, and 12 to 24 inches) from the CR-LTE, WP-LTE, and GP and analyzed them for SOC.

The grassland had the highest amount of SOC content in individual soil depths as well as in the 0- to 60-centimeter profile. SOC under grassland was 87.4 megagrams per hectare, which was considerably higher than levels observed under all WW-SF (CR-LTE) as well as under the continuous cropping (WP-LTE) systems.

Crop residue long-term experiment at at Columbia Basin Agricultural Research Center, near Pendleton OR . Photo by Stephen Machado.

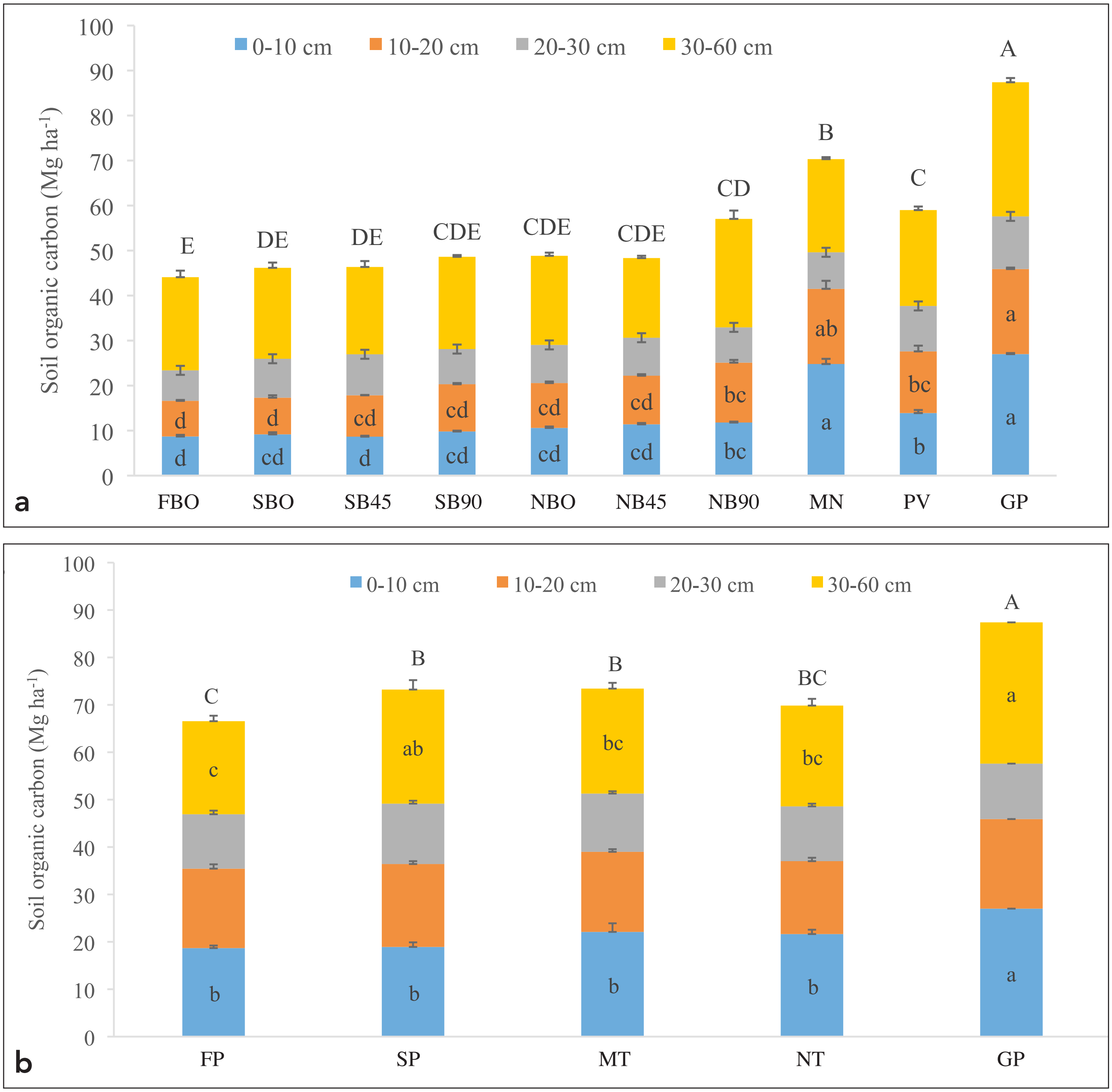


Figure 1. *Soil organic carbon content in soil profiles of (a) crop residue and (b) wheat-pea long-term experiments and a nearby undisturbed grassland in 2010. Segments with the same lowercase letters indicate no significant difference among treatments within a sampling depth, and those with the same uppercase letters indicate no significant difference among treatments in the 0- to 60-centimeter depth profile. Part a: FB = fall burn, SB = spring burn, NB = no burn, MN = manure, PV = pea vine, GP = grassland pasture. 0, 45, and 90 refer to kilogram nitrogen per hectare per crop. Part b: FP = fall plow, SP = spring plow, MT = medium-till, NT = no-till, GP = grassland pasture.*

All WW-SF systems were losing SOC in the 0- to 60-centimeter soil profile in the last century. SOC loss from the WW-SF systems was lowest under manure treatment, and the SOC in these systems was only 20% less than that under GP (Figure 1a). SOC under manure application was significantly higher than all other treatments in the WW-SF system. The loss of SOC under the WW-SF system was highest when residues were burned in the fall, with 68% and 50% less SOC in the 0- to 10-centimeter and 0- to 60-centimeter depths, respectively, compared to the GP SOC.

In WP-LTE, SOC content was 30% to 44% less than that of the grassland (Figure 1b). The SOC content was not significantly different among WP-LTE treatments in the 0- to 10-, 10- to 20-, and 20- to 30-centimeter depths. When the 0- to 60-centimeter profile was considered, however, SOC was not significantly different among spring plow, minimum-till, and no-till. All WP-LTE treatments increased SOC over time. The rate of SOC gain from 1995 to 2010 was 0.04, 0.49, 0.53, and 0.37 megagrams per hectare per year in fall plow, spring plow, minimum-till, and no-till systems, respectively, in the 0- to 60-centimeter soil depth.

Winter pea crop rotation study at Ritzville, WA

William Schillinger (william.schillinger@wsu.edu) WSU, Ron Jirava (farmer collaborator), John Jacobsen WSU, and Steve Schofstoll WSU

IMPACT

Winter pea is a low-input crop that shows good yield potential in the typical winter wheat, summer fallow zone of the inland Pacific Northwest. Average winter pea yield over a three-year period near Ritzville, WA, was 2,288 pounds per acre. Farmers have expressed interest in growing winter pea, and acreage of this crop is expected to increase in the near future.

A long-term winter pea (WP) cropping systems experiment was initiated at the Ron Jirava farm near Ritzville, WA, in the summer of 2010. The objective of the experiment is to determine the suitability of winter peas (Figures 1 and 2) in the low-precipitation zone where winter wheat, summer fallow (WW-SF) has been the dominant rotation for more than 120 years.

The WP variety 'Windham' was selected for inclusion in the experiment based on the experience and recommendation of Howard Nelson of Central Washington Grain Growers in Wilbur, WA. 'Windham' is a feed pea with upright growth habit and good cold tolerance. It can be direct combined with a regular header (that is, swathing and/or a pick-up header are not required). Winter pea has a large seed that is capable of emerging through 5 inches of soil cover.

Two three-year crop rotations were tested in the experiment: (1) WP, spring wheat (SW), SF versus (2) WW-SW-SF. The experimental design is a randomized complete block with four replicates of each treatment. All treatment combinations are present each year, making a total of 24 plots. All plots are 100 feet long.

Yield of 'Windham' WP was 1,958, 2,820, and 2,086 pounds per acre in 2011, 2012, and 2013, respectively, for a three-year average yield of 2,288 pounds per acre. Winter pea was killed by cold temperatures during the winter of 2013-14. We therefore replanted the plots to the edible 'Banner' spring pea on April 3. The yield of

Figure 1. *Winter pea (right) and winter wheat (left) in early May. Photo by Bill Schillinger.*

spring pea in 2014 was 778 pounds per acre. Spring wheat yield after WP versus WW was 30 versus 32 bushels per acre in 2012, 44 versus 40 bushels per acre in 2013, and 16 versus 15 bushels per acre in 2014 (Table 1).

WP used significantly less soil water than WW (Table 1). However, over the winter months, a higher percentage of precipitation was generally stored in the soil following WW compared to WP (Table 1). The reason for this are: (1) very little WP residue remains on the soil surface after harvest compared to WW, and (2) the drier the soil, the more precipitation will be stored in the soil over the winter. The end result was that when SW was planted in late March, soil water following WP and WW was the same (Table 1).

We will continue this experiment until at least 2017. Winter pea has shown high yield potential in this experiment where average annual precipitation is only 11 inches. We initiated a new long-term study at the Jirava farm in 2014 where we are growing WP in a four-year no-till crop rotation consisting of WP, chemical fallow (CF), winter triticale, CF. In addition, we initiated a replicated WP varietal trial at the WSU Lind Dryland Research Station in 2014.

Figure 2. *Winter pea in late May. Photo by Bill Schillinger.*

Table 1. *Soil water content and grain yield for spring wheat (SW) in two three-year rotations where the preceding crop was winter pea (WP) or winter wheat (WW).*

	Timing in fallow period				
	Beginning (late August)	**Spring (mid-March)**	**Overwinter gain**	**PSE[1] (%)**	**Grain yield (bushels per acre)**
	Soil water content (in.)				
2013-14					
Rotation					
SW after WP[2] in 3-year rotation	7.3	10.6	3.3	49	16
SW after WW[3] in 3-year rotation	6.5	9.5	3.0	45	15
p-value	ns	ns	ns		ns
2012-13					
Rotation					
SW after WP in 3-year rotation	7.4	12.6	5.2	62	44
SW after WW in 3-year rotation	6.4	12.5	6.1	73	40
p-value	0.03	ns	ns		0.01
2011-12					
Rotation					
SW after WP in 3-year rotation	6.8	8.2	1.4	34	30
SW after WW in 3-year rotation	5.3	8.4	3.1	75	32
p-value	0.01	ns	0.02		ns

[1] Overwinter precipitation storage efficiency (PSE): 2011-12 = 4.11 in.; 2012-13 = 8.33 in.; 2013-14 = 6.69in.

[2] Winter pea yields for 2011, 2012, 2013, and 2014 were 1,958, 2,820, 2,086 and 778 pounds per acre, respectively.

[3] Winter wheat yields for 2011, 2012, 2013, and 2014 were 77, 85, 87, and 50 bushels per acre, respectively.

PSE = overwinter precipitation storage efficiency (e.g., the percentage of precipitation occurring from harvest in early August until late March that was stored in the soil).

Economic impacts of delayed planting: Field trial results

Kathleen Painter (kpainter@uidaho.edu) UI, Dave Huggins USDA-ARS, and Shelley Jones WSU

Growers are anxious to get their crops planted and growing each fall and spring, and for good reason. A day's delay in seeding resulted in yield decreases per acre of 34 pounds for spring barley, 33 pounds for spring wheat, 31 pounds for winter wheat, 22 pounds for spring canola, and 18 pounds for spring peas in a nine-year no-till cropping systems trial on the Cook Agronomy Farm (CAF) near Pullman, WA (Table 1). Using average marketing year prices received by growers in the REACCH production region for 2009 through 2013, we calculated that the daily penalty was highest for spring canola at $4.46 per acre, followed by hard red spring wheat at $3.83, hard red winter wheat at $3.38, barley at $2.94, and peas at $2.65.

IMPACT

Delayed planting causes financial hardship for growers. In addition, it can affect crop insurance claims. Nine years of planting, yield, and price data on no-till wheat-based systems from the Cook Agronomy Farm, an official Long-Term Agroecosystem Research (LTAR) site designated by the U.S. Department of Agriculture, provide results that are sufficiently robust to assist growers, educators, and policymakers with planting decisions.

We calculated these results by comparing the average change in yield per day to the crop yield for the earliest planting date at CAF for this nine-year time period. Spring crops were planted as early as March 24 and as late as May 12, a span of 49 days. Winter wheat planting dates ranged from September 30 to October 25, a range of 25 days. While spring barley had a slightly larger decline in daily yield than the other crops, the price per pound was higher for spring canola, hard red spring wheat, and winter wheat, resulting in larger financial penalties per day for delayed planting of these crops.

The earliest planting date for no-till hard red spring wheat during the period of study was March 24, while the latest planting date was May 5, a 42-day span (Figure 1). The highest spring wheat yield of 82 bushels per acre occurred with an April 3 planting date in 2004. March planting dates resulted in spring wheat yields of 74 bushels (March 24 planting) and 60 bushels (March 26 planting). In the last two years of the study, spring wheat was planted in early May, with yields of 42 bushels and 61 bushels per acre. Obviously, planting date is not the only variable that determines crop yield, but it is an important factor with a strong correlation.

Winter wheat yield was highest at 93 bushels per acre with a September 30 planting, but the second highest yield of 91 bushels per acre occurred following an October 25 planting (Figure 2). The yield impact by planting date for fall-planted crops is weaker than for spring-planted crops due to the longer time period, effects of overwinter precipitation, and other weather-related variables.

Spring barley yields were lowest, at 1.45 and 1.61 tons per acre, when the crop was planted in early May, although a May 12 planting resulted in a 2-ton yield in 2009 (Figure 3). When barley was planted by April 16, yields were 2.3 tons per acre or more. Spring canola yields exceeded 2,700 pounds per acre when the crop was planted on March 26 in 2001, and on April 12 in 2004, although an April 8 planting resulted in a very low yield of 1,059 pounds per acre in 2005 (Figure 4). Obviously, factors other than planting date affected the spring canola crop in that year.

Growers also face planting deadlines imposed by crop insurance programs. The intent of these planting deadlines is to ensure that the growing season is adequate for crop production. During years of adverse planting weather, growers may end up using the "prevented planting" provision, which provides an indemnity based on the fact that they were unable to seed by the planting

Table 1. *Yield and economic impacts of a day's delay in planting based on field-scale yield results with no-till planting at the Cook Agronomy Farm, 2001 to 2009, using five-year average regional farmgate crop prices for 2009 to 2013 (U.S. Department of Agriculture National Agricultural Statistics Service).*

				Impact of planting delay		Planting dates	
Crop	Unit	Price[1]	Price per unit	Pounds per day	Cost per day	Earliest	Latest
Spring canola	cwt	$20.10	$0.20	-22.21	-$4.46	March 26	May 12
Hard red spring wheat	bu	$7.04	$0.12	-32.68	-$3.83	March 24	May 5
Hard red winter wheat	bu	$6.57	$0.11	-30.90	-$3.38	Sept 30	Oct 25
Spring barley	ton	$171.58	$0.09	-34.31	-$2.94	March 26	May 12
Spring peas	cwt	$14.48	$0.14	-18.27	-42.65	April 24	June 2

[1] Prices are 2009-2013 marketing year average prices received by farmers, USDA-NASS
bu = bushels, cwt = hundredweight

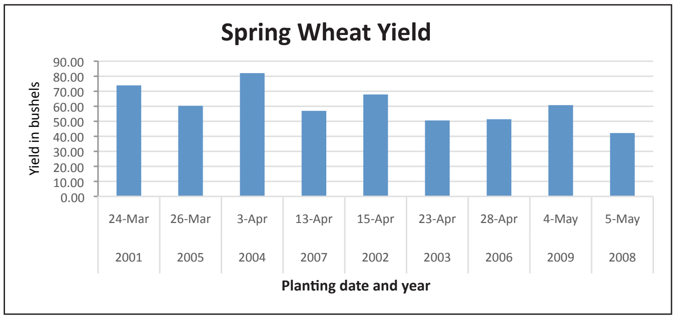


Figure 1. *Relationship between planting date and yield for no-till hard red spring wheat, 2001 to 2009, Cook Agronomy Farm, Pullman, WA.*

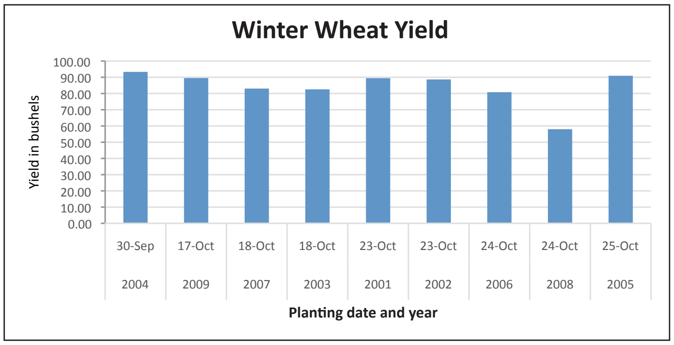


Figure 2. *Relationship between planting date and yield for no-till hard red winter wheat, 2001 to 2009, Cook Agronomy Farm, Pullman, WA.*

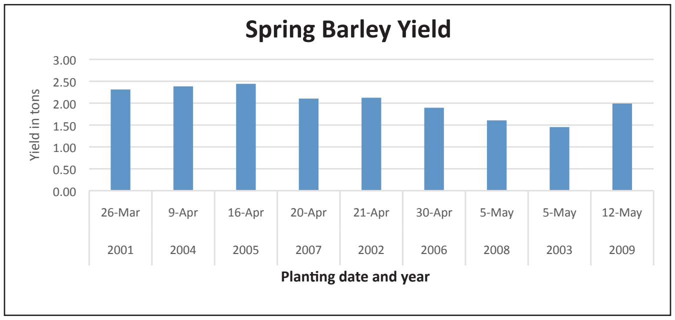


Figure 3. *Relationship between planting date and yield for no-till spring barley, 2001 to 2009, Cook Agronomy Farm, Pullman, WA.*

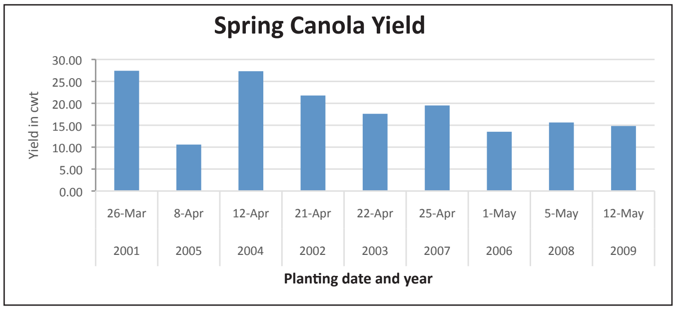


Figure 4. *Relationship between planting date and yield for no-till spring canola, 2001 to 2009, Cook Agronomy Farm, Pullman, WA.*

deadline. They cannot seed past this date and receive the indemnity. The correlation between planting date and yield, while not perfect, is obvious from these nine years of data.

Direct seeding has some advantages over conventional tillage in terms of timely planting, as fewer preplanting tillage passes are needed to prepare the ground for planting. During cool, wet springs, however, direct-seeded ground tends to remain cool and wet longer than conventionally tilled land. While there are many more factors affecting yield than planting date, time of planting is a strong determinant of yield potential.

Photo by Brad Stokes.

Crop diversity and intensity in Pacific Northwest dryland cropping systems

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Increasing cropping system diversity (e.g., developing different crop options) as well as intensity (e.g., less fallow) are two strategies that can help both mitigate climate change and provide options for adaptation. Relevant questions include (1) How can we assess cropping system diversity and intensity from a regional perspective? (2) What REACCH research efforts are addressing this issue? and (3) What is our current situation and future prognosis under climate change?

IMPACT

Growers will benefit from more crop options that diversify and intensify current cropping systems. REACCH efforts are helping to define agronomic factors and advance the feasibility of alternative cropping system strategies. In turn, these research efforts will contribute to the development of cropping systems that help mitigate climate change as well as provide options for adapting to future shifts in weather and economic uncertainties.

Dryland cropping systems

Decisions regarding crop choice are a function of interactive biophysical (e.g., precipitation, soil) and socioeconomic (e.g., commodity prices, fertilizer costs) factors and are expressed geographically through land use and cover. Spatially georeferenced cropland use/cover data are available annually for the REACCH region since 2007 through the National Agricultural Statistics Service (NASS) (Figure 1). We have used these data to define relevant agroecological classes (AECs), consisting of three dryland AECs and one irrigated AEC, for the REACCH region (Figure 2). Once defined, crop choices and shifts in cropland use/cover as well as AECs can be characterized over time (Figures 2 and 3).

The grain-fallow AEC comprises the largest acreage, nearly twice that of the annual cropping and annual crop-fallow transition AECs. Winter wheat is the predominant crop grown. In the annual cropping AEC, spring cereals (wheat and barley) as well as grain legumes and canola complement winter wheat, which was 49% of the crop acreage in 2007. Fallow largely replaces grain legumes and canola in the annual crop-fallow transition AEC, while spring cereal acreage persists. The grain-fallow AEC is almost evenly split between winter wheat and fallow, with small percentages of spring wheat (Figure 3).

Not surprisingly, crop diversity, assessed for each AEC using Shannon's diversity index, was low for all AECs but lowest for the grain-fallow AEC and highest for the annual cropping AEC (Figure 4). Changes in diversity using this measure appear quite modest for the 2007 through 2013 period, though diversity trends upward for the annual cropping and fallow transition AECs (Figure 4). Basically, a Shannon's diversity index for a region that grew one crop would be zero. In our example, we include fallow as part of the analysis. One interpretation of these findings is that regions with low diversity would be more vulnerable to shifts in weather, commodity prices, and input costs, as little opportunity exists to vary crop choices. On the other hand, replacement of crops with fallow can lend stability to winter wheat performance.

REACCH research on developing improved cropping system strategies

The grain-fallow AEC has traditionally relied on fallow practices to store soil profile water and maintain seed-zone moisture for winter wheat establishment and yield stability. Challenges for this

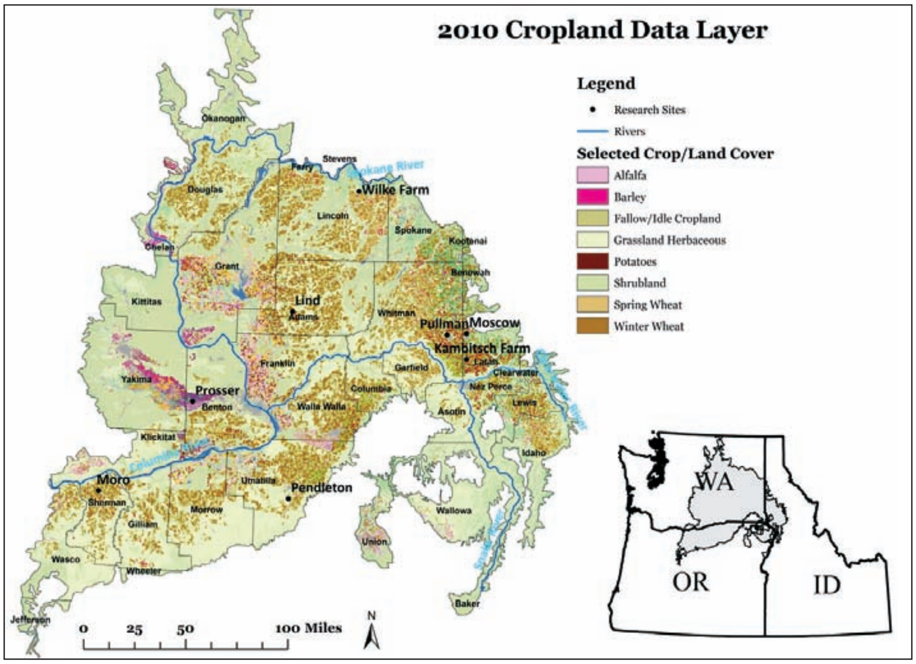


Figure 1. *2010 cropland data layer for the REACCH region.*

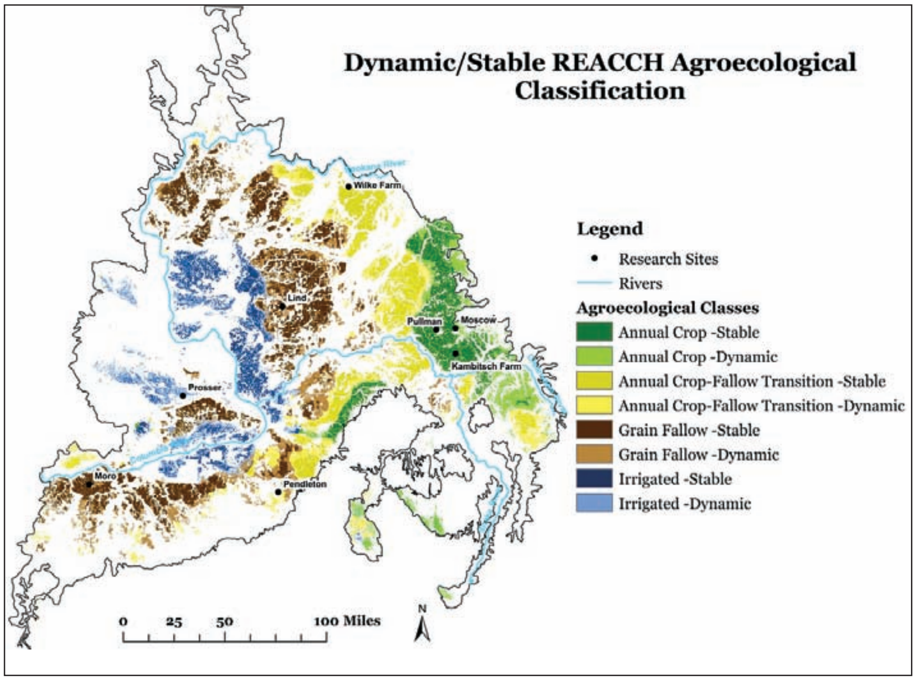


Figure 2. *Agroecological classes (AECs) for the REACCH region. Stable AECs have had the same AEC for the years 2007 through 2013, while dynamic AECs represent areas where the AEC has changed for one or more years during the same time period.*

AEC include winter annual grassy weeds (e.g., feral rye, downy brome, jointed goatgrass) as well as vulnerability to wind erosion. Annual spring cropping has not been economical to date, and current research efforts are directed toward diversifying the winter wheat leg of the grain-fallow cycle. Candidates for replacing winter wheat (WW) include winter triticale (WT), winter canola (WC), winter peas (WP), and facultative wheat. Schillinger and co-workers have shown that early-planted WT produced an average of 18% greater grain yield than early-planted WW, while late-planted WT produced equal grain yield compared to early-planted WW near Ritzville, WA, averaged over four years. Greater flexibility in planting date could reduce the necessity for tillage-intensive practices aimed at maintaining seed-zone water for late August sowing targets. In turn, opportunities for reduced tillage and inclusion of cover crops might be increased. Young and co-workers have demonstrated in research near Ralston, WA, that the relatively tall WT stubble (particularly when combined with a stripper header) in no-till systems can result in reduced soil temperatures and greater seed-zone water, furthering opportunities to establish small-seeded crops such as WC. Including WC in traditional grain-fallow rotations would provide rotation benefits with respect to grassy weed and disease management. Schillinger and co-workers have also researched planting date alternatives for WC establishment. Earlier seeded WC under more favorable seed-zone water conditions can result in more successful stand establishment. But trade-offs exist, as larger, earlier established WC consumes more stored soil water than later seeded WC, which could adversely affect winter survival as well as final yield. Also near Ritzville, WA (11- to 13-inch annual precipitation), Schillinger and co-workers have shown that WP exhibit good winter hardiness and reasonable yields, averaging 2,200 pounds per acre from 2011 through 2013. Rotations of WW, spring wheat (SW), and fallow (F) are being compared with WP-SW-F rotations.

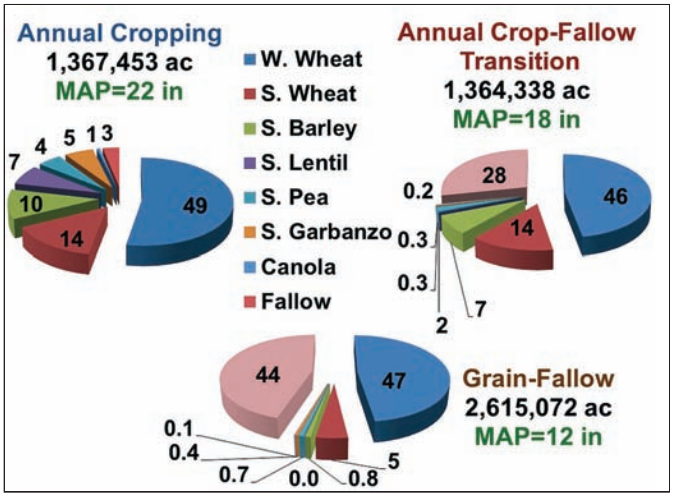


Figure 3. *Crop and fallow percentages as well as total area for the three dryland agroecological classes in 2007. (MAP refers to mean annual precipitation.)*

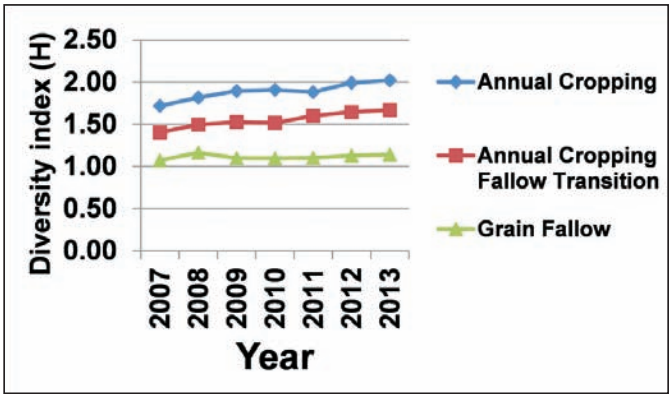


Figure 4. *Shannon's diversity index for each agroecological class from 2007 through 2013.*

In the annual crop-fallow transition AEC, research has emphasized opportunities to replace fallow, thereby intensifying cropping systems. Machado and co-workers, near Pendleton, OR (17-inch annual precipitation), have demonstrated that replacing fallow with spring pea can produce pea yields ranging from 750 to 3,000 pounds per acre while having little impact on subsequent WW yields as compared to fallow. Intensification of cropping systems with this grain legume that uses relatively low amounts of water is an exciting option that growers are beginning to adopt.

Diversification of direct-seed cropping systems has been a research goal for the Cook Agronomy Farm (CAF). Huggins and co-workers have demonstrated that spring canola as well as garbanzo beans (chickpeas) can be readily established into heavy WW stubble using no-tillage, leading to excellent yields. Spring canola yields, however, have been very sensitive to planting date, with yield decreasing by about 50 pounds per acre per day after an April 15 sowing date. Analyzing enterprise budgets comparing crops at the CAF, Painter and co-workers reported that garbanzo beans were one of the most profitable crops grown, surpassing WW in some years.

Acreage of canola and grain legumes increased substantially within the REACCH region from 2007 through 2013 (Figures 5 and 6). Canola acreage increases have been predominantly in the annual cropping zone, ranging from a low of 4,200 acres in 2011 to nearly 30,000 acres in 2013 (Figure 5). Total acreage of canola across all AECs was also highest in 2013 at nearly 65,000 acres. Increases in canola production have no doubt been spurred by favorable prices, establishment of regional processing facilities, and efforts of the WA biofuels cropping systems and REACCH-supported teams led by Bill Pan and co-workers that have provided research on agronomic factors and feasibility. Grain legumes have also benefited from favorable prices, although at this point the opportunity has primarily been explored in the annual cropping AEC, where grain legume acreage increased from a low of 19,000 acres in 2011 to over 31,000 acres in 2013. Much of this increase in grain legume production was from garbanzo bean (chickpea) (Figure 6). Interestingly, spring pea is currently the most prominent grain legume in the annual crop-fallow transition AEC, likely reflecting its relatively modest requirements for water. However, the potential for garbanzo bean production throughout the more dryland cropping AECs is still relatively unexplored, particularly as a replacement option for WW. Finally, although acreage of canola and grain legumes has increased, the total amount of fallow for the REACCH region remained relatively constant from 2007 through 2013, indicating that diversification has not replaced fallow, but rather has replaced other crops such as spring cereals (Figure 5).

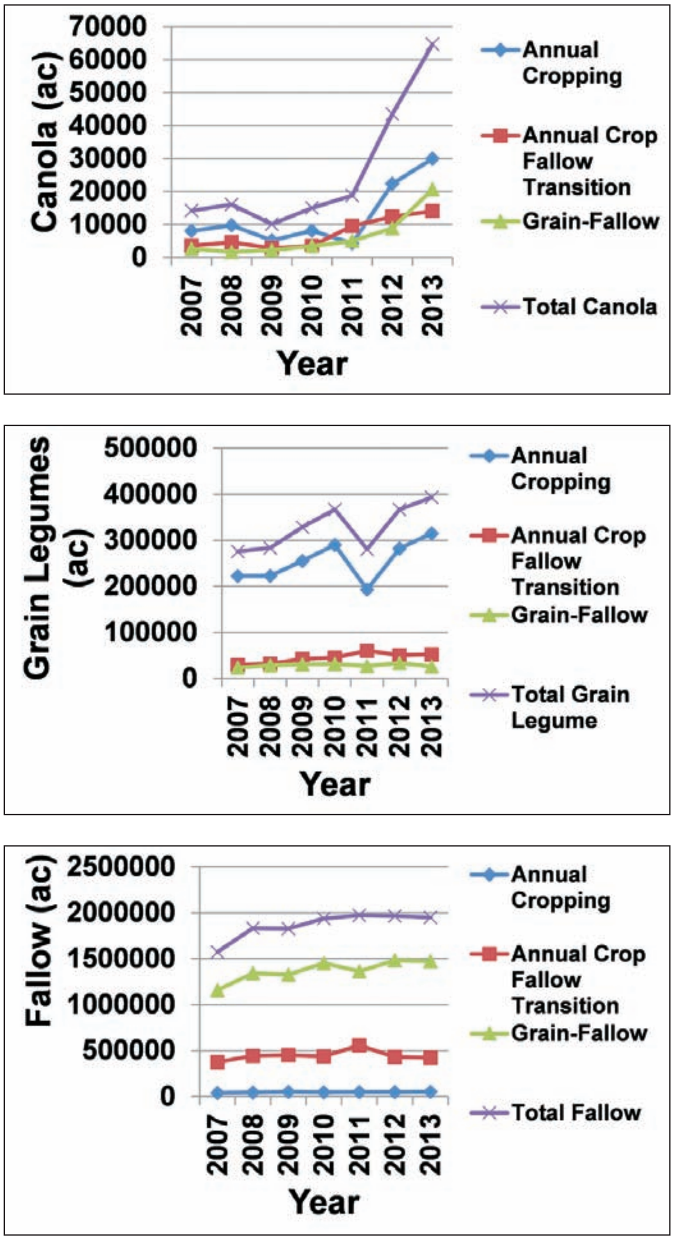


Figure 5. *Changing acreage of canola, grain legumes, and fallow by agroecological class from 2007 through 2013.*

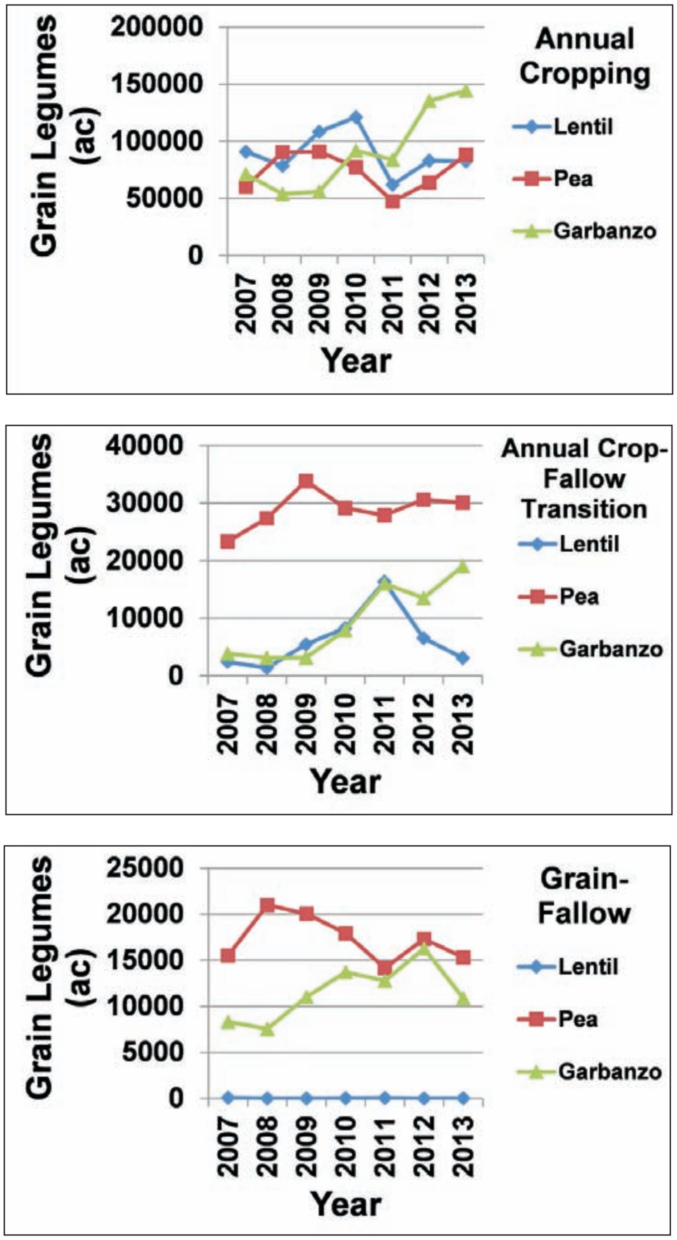


Figure 6. *Changing acreage of lentil, pea, and garbanzo bean for each agroecological class from 2007 through 2013.*

Future research efforts will continue to advance the potential for increasing cropping system diversification and intensification. Integration of process-oriented modeling and economic efforts through REACCH will further advance decision support. Complementarily, the AEC framework will continue to support efforts that (1) provide information on annual crop choices and help to assess shifts in cropland use/cover over time; (2) geospatially quantify and identify opportunities for crop diversification and intensification; (3) evaluate biophysical (e.g., climate, soils, terrain) and socioeconomic (e.g., commodity prices) drivers of crop choice, thereby aiding in the development of decision support tools; and (4) geospatially target research, education, and outreach efforts that enable future crop diversification and intensification.

Photo by Leigh Bernacchi.

Suppression of *Rhizoctonia bare patch* in long-term no-till cropping systems

William Schillinger (william.schillinger@wsu.edu) WSU and Tim Paulitz USDA-ARS

The soilborne fungus *Rhizoctonia solani* AG-8 is a major concern for farmers who practice no-till farming in the inland Pacific Northwest. Bare patches caused by *Rhizoctonia* spp. first appeared in 1999 during year 3 of an 18 year no-till cropping systems experiment near Ritzville, WA (10.6 inches of annual precipitation). We mapped the extent and pattern of patches from 1999 to 2014 at the 20 acre study site with a backpack-mounted GPS equipped with mapping software. Bare patches appeared in winter and spring wheat (*Triticum aestivum*), spring barley (*Hordeum vulgare*), yellow mustard (*Brassica hirta*), and safflower (*Carthamus tinctorius*) (Figure 1).

IMPACT

Rhizoctonia bare patch is a soil-borne fungal disease that appeared in year 3 of a long-term no-till cropping systems experiment near Ritzville, WA. Bare patches appeared in all crops and, at the peak of the infestation, occurred on up to 18% of land area. Areas of bare patches began to decline in year 8 and reached near zero levels by year 11. This study provided the first direct evidence of natural decline of *Rhizoctonia* bare patch in no-till cropping systems in North America.

At its peak in years 5 to 7, bare patches occupied as much as 18% of total plot area in continuous annual monoculture spring wheat (Figure 2). The area of bare patches began to decline in year 8 and reached near zero levels by year 11. No measurable patches were present in years 12 to 18. Patch area was significantly greater in continuous spring wheat compared with spring wheat grown in a two-year rotation with spring barley (Figure 2). Additionally, the 18 year average grain yield for spring wheat in rotation with spring barley was significantly greater than for continuous spring wheat. Russian thistle (*Salsola tragus*), a troublesome broadleaf weed with a fast-growing taproot, was the only plant that grew within the patches (Figure 3). This is the first direct evidence of natural suppression of *Rhizoctonia bare patch* with long-term no-till cropping in North America. This suppression also developed in a rotation that contained broadleaf crops (yellow mustard and safflower) in all but five years of the study, and the suppression was maintained when safflower was added back to the rotation.

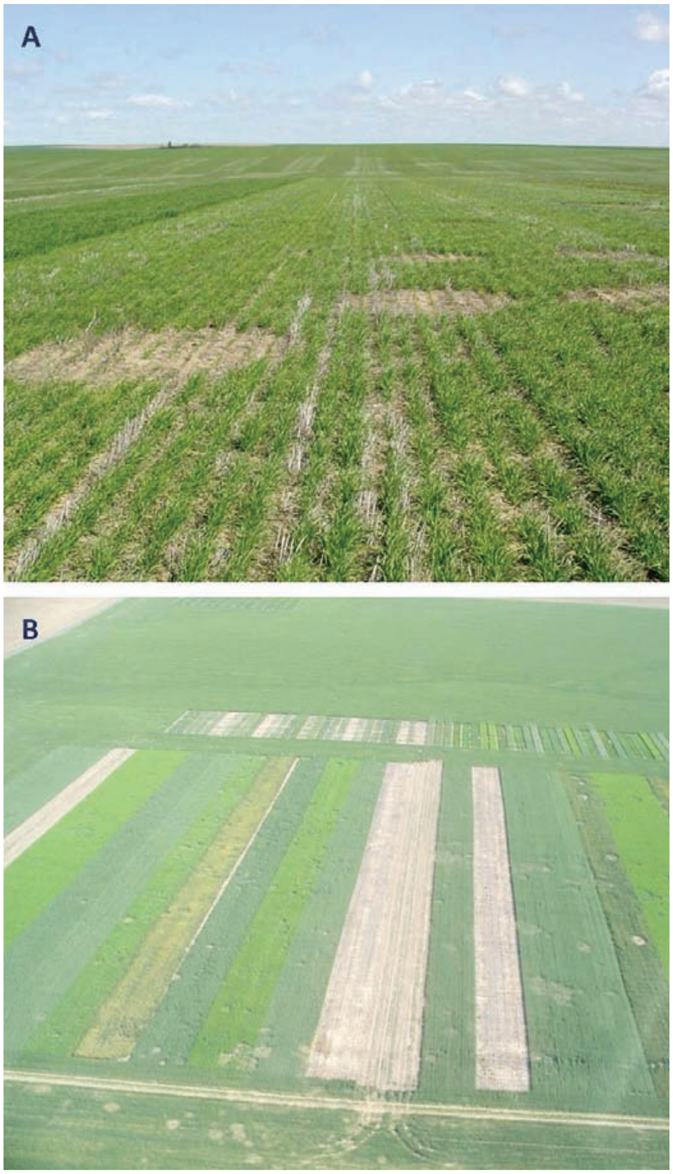


Figure 1. *Bare patches caused by* Rhizoctonia solani AG-8 *in a long-term no-till cropping systems experiment near Ritzville, WA. (a) Spring barley (left) and spring wheat (right) during the juvenile growth period in early May 2003. (b) Aerial overview of one replicate of the large-scale experiment in early July 2006, at which point* Rhizoctonia bare patch *was in decline. Photo by Bill Schillinger.*

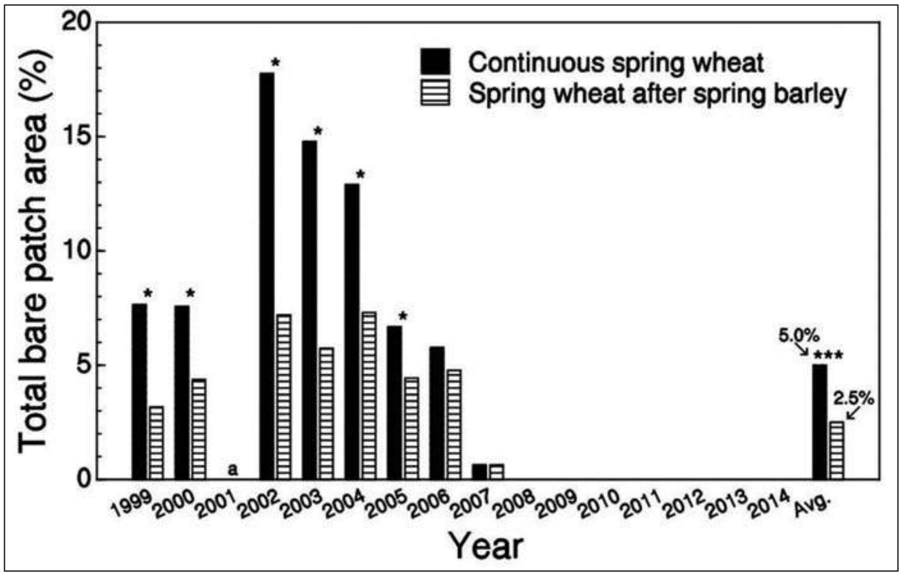


Figure 2. *Total bare patch area caused by* Rhizoctonia solani AG-8 *was significantly greater during years 3 to 9 (1999 to 2005) in continuous annual spring wheat compared to spring wheat grown in a 2-year rotation with spring barley. The crops were grown no-till in all years. At its peak in 2002, bare patches occupied as much as 18% of total plot area. Bare patch area began to slowly decline in 2003 and, by 2008 and thereafter, was nearly totally suppressed.*

[a] *Patch area was not measured in 2001 due to severe drought, which made it difficult to discern bare patches from water-stressed crops.*

**** Significantly different at $P < 0.001$.*

Figure 3. *Russian thistle, shown here in spring barley, was the only plant that grew in bare patches. Its taproot was able to penetrate through the layer of* Rhizoctonia *inoculum to access soil water present beneath patches. Cereal and oilseed crops grown in the large-scale experiment did not send roots underneath the bare patches, thus leaving "islands" of stranded water. Photo by Bill Schillinger.*

Drought stress alters a host-vector-pathogen interaction

Seth Davis (thomasd@uidaho.edu) UI, Nilsa Bosque-Pérez UI, Nathaniel Foote UI, Troy Magney UI, and Sanford Eigenbrode UI

Viral pathogens are ubiquitous and can impose limitations on agricultural productivity. Despite their prevalence, host-virus interactions are seldom considered as potentially beneficial, and until recently studies of plant viruses focused primarily on the damaging physiological effects of infection on host plants. However, recent evidence suggests that virus infection is not always harmful to plants, and many viruses found in plant tissues exhibit few, if any, symptoms in their hosts, leading researchers to question whether plant viruses have ecological significance that extends beyond their role as pathogens.

IMPACT

Plant viruses do not always harm their hosts, and in some situations may even benefit them. Our recent research suggests that Barley yellow dwarf virus–*Padi-avenae* virus (BYDV) infection does not harm host wheat plants when water is limited, and that under severe drought stress, infection may help plants to survive.

We tested whether environmental stress alters host-virus interactions in an agro-ecosystem comprising an herbivore virus vector (*Rhopalosiphum padi* L.), wheat, and an insect-borne viral pathogen (Barley yellow dwarf virus–*Padi-avenae* virus, BYDV-PAV). Our approach evaluates interactions between water stress and virus infection in this system. Prior to experiments testing interactions between water stress and host plant infection, we confirmed that plant water stress could be reliably manipulated by top-watering plants at different quantities. We performed experiments to answer the following two questions: (1) Do water quantity and pathogen infection interact to affect host plant growth and seed set when watering treatments are applied over the life of hosts? and (2) Does host infection have consequences for host vital rates when plants are challenged by drought and subsequently allowed to recover? For this question we tested two different types of water stress: short-term water scarcity and longer-term water withholding.

Results. There were significant interactions between host infection status and water quantity when watering treatments were applied over the lifetime of plants. Under low water there was no significant difference in the total number of germinating seeds resulting from plant infection status, indicating a pattern consistent with higher seed set by noninfected plants at high water inputs but no effect of pathogen infection on seed set at low water inputs (Figure 1).

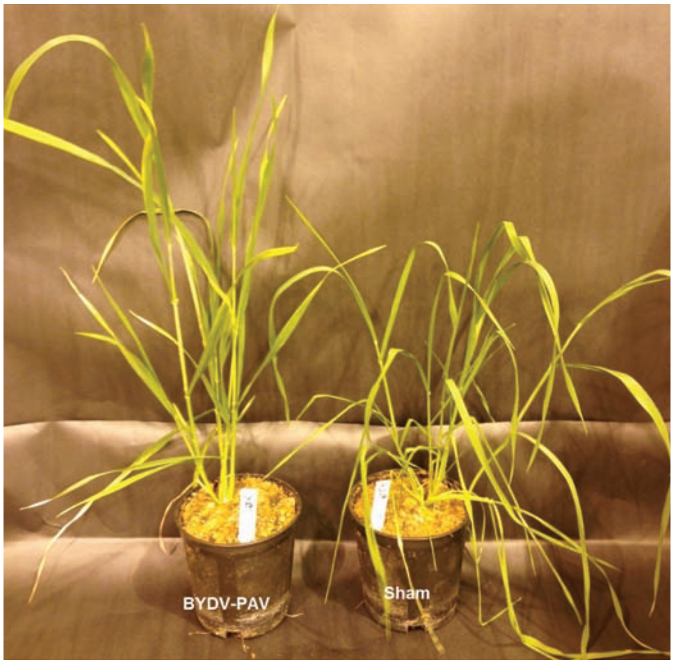


Figure 2. Triticum aestivum cultivar *'JD' following a challenge with seven days of water scarcity. Infected plants were visibly more turgid and robust at the end of the experimental period. Photo by Seth Davis.*

When water inputs were low, infected plants retained more water (Figure 2). Before we imposed water scarcity, host infection status had no effect on leaf water potential, but following a seven-day period of water scarcity, BYDV-PAV-infected plants had significantly higher leaf water potentials than either sham-inoculated or undamaged plants. After we resumed watering, host infection status had no effect on seed set, seed mass, germination frequency, or total number of germinated seeds. However, aboveground biomass was greater for virus-infected plants at the end of the experiment than for either sham-inoculated or undamaged plants. After long-term water stress (withholding) followed by recovery, infected plants surpassed uninfected control plants in biomass growth, seed set, absolute and relative seed germination frequency, and seed mass. Also, the onset and progression of water stress symptoms were delayed for infected host plants in comparison to uninfected control plants (Figure 3).

Discussion. Our results suggest that applying moderate stress through water limitation and withholding shifted host-pathogen interaction from negative to neutral over the lifetime of hosts, but that host wheat plants actually benefited from the infection when abiotic stress became severe. These effects translated directly to host vital rates and productivity, with infected hosts producing more viable seed under severe abiotic stress. Altogether, our results are consistent with a hypothesis of context dependency in this pathosystem and suggest that environmental factors may mediate disease dynamics in agroecosystems, potentially favoring coexistence of hosts, vectors, and pathogens in stressful environments.

Several physiological hypotheses could underlie the patterns we describe here, particularly hydraulic failure, carbon starvation, and biochemical induction. We are focusing our efforts on determining whether systemic induction of broadly bioactive phytohormones in response to infection may be responsible for the effects we observed. In particular, the abscisic acid stress hormone pathway has been implicated in conferring tolerance to water stress following viral infection. There is significant genetic variation in wheat for the induction of this pathway following virus infection, which may have important biotechnology applications and could allow geneticists to select for wheat resistance to drought stress using pathways that are elicited by viruses. We conclude that the ecology of agricultural viruses is not intuitive and cannot be understood without considering both costs and benefits to host organisms: in the wheat-BYDV-aphid system, we propose that control efforts for viruses may not be necessary in drought years. Future research in this area will evaluate how these complex symbiotic interactions may be exploited to promote agroecological resilience under climate change, with efforts focused on identifying genetic patterns underlying the effects we report here.

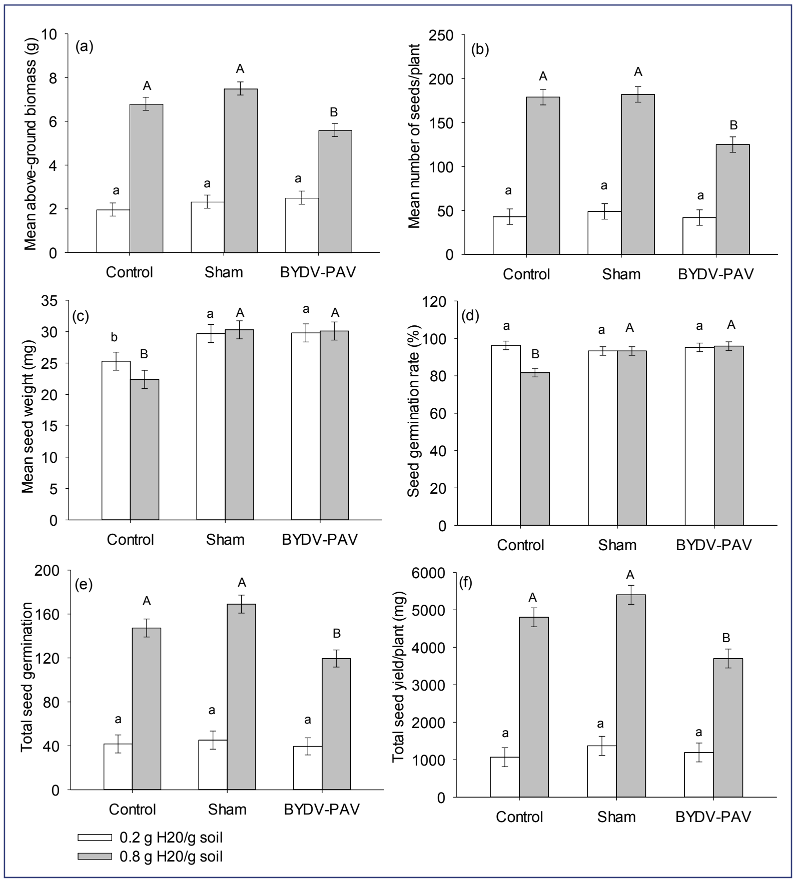


Figure 1. *Interaction between water quantity and* Barley yellow dwarf virus–Padi-avenae *virus (BYDV-PAV) infection on (a) aboveground biomass, (b) seed set, (c) seed weight, (d) seed germination frequency, and (e) total number of germinating seeds for virus- and sham-inoculated* Triticum aestivum*, and control plants. Gray bars denote the high water treatment (0.8 g water per gram soil), and black bar bars denote the low water treatment (0.2 g water per gram soil). Error bars show ± SE. Lowercase letters denote Tukey's honest significant difference (HSD) test within the low-water group, and uppercase letters denote Tukey's HSD test within the high-water group.*

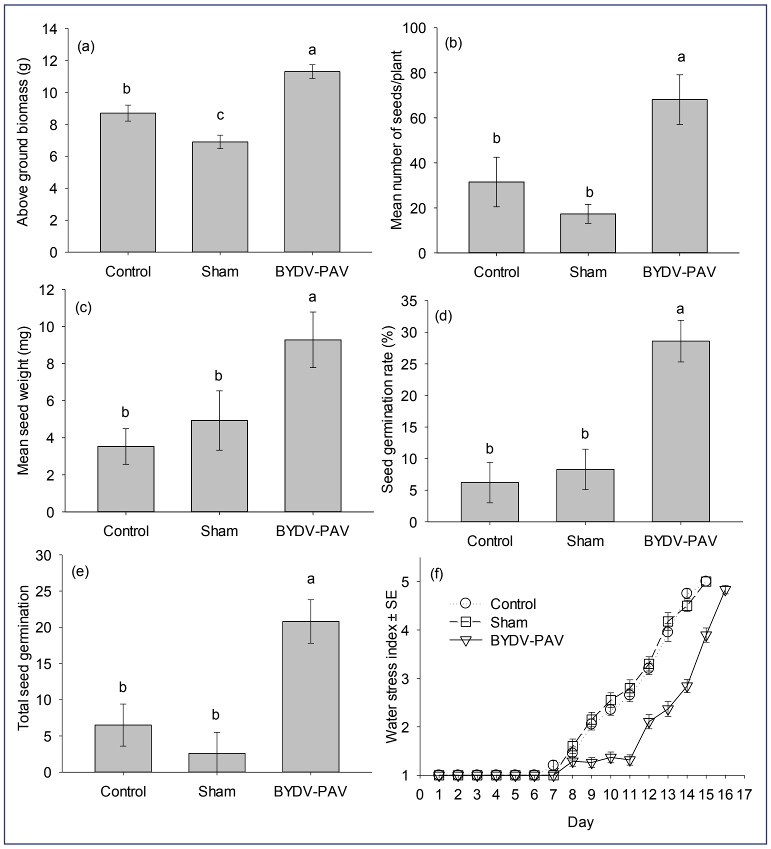


Figure 3. *Plant responses following water withholding and recovery. Differences in (a) aboveground biomass, (b) seed set, (c) seed mass, (d) seed germination frequency, and (e) total germination, according to infection status of* Triticum aestivum *following 15-day water withholding and recovery. (f) Time series showing the onset and progression of visual water stress symptoms in* T. aestivum *following water withholding. In all panels, letters indicate Tukey's honest significant difference (HSD) test. BYDV-PAV =* Barley yellow dwarf virus–Padi-avenae *virus.*

Wireworm distribution and ecology in southern ID

Arash Rashed (arashed@uidaho.edu) UI and Juliet Marshall UI

In recent years, wireworms, the larval stage of click beetles (Coleoptera: Elateridae), have emerged as a major threat to cereal production in the Pacific Northwest (Figures 1 and 2). Historically, wireworm damage was controlled with environmentally persistent insecticides, which are now banned due to environmental and health concerns. Shortly after those chemicals were banned, wireworms resurged. The available registered insecticides for wireworm control in cereals, neonicotinoids, have provided very limited to no protection.

IMPACT

The effectiveness of integrated pest management approaches to controlling wireworms in cereals (and other crops) relies on a clear understanding of the species of wireworm present and their ecology. Such an understanding would lead to the development of more sustainable management practices.

Regardless of the underlying cause of the resurgence, the failure of the new insecticides to provide uniform protection has been attributed to species-dependent susceptibility as well as very high wireworm pressure. Recently, more emphasis has been placed on exploring integrated pest management approaches to achieve sustainable pest control. The effectiveness of such approaches, however, requires a clear knowledge of the present species and their interaction with the environment.

To help develop this knowledge, we started a species survey in central and southern ID. We placed more than 30 traps in different locations across ID, including two traps in Moscow (Figure 3). We started trapping in June 2014, using traps placed below the soil surface. After harvest, in August and September, we continued our surveys at soil depths of 6, 12, and 24 inches. The collected data on numbers and species composition will be evaluated in relation to environmental variables such as temperature and precipitation.

Data collected during the past four months indicate that various wireworm species appear in the solar traps at different times. Multiple species may be present within the same field. Unexpectedly, the solar traps continued to attract wireworms in August and September in central and eastern ID. Our latest data indicate that the prevalent species collected in traps changed toward the end of the season. The majority of the collected species has been from the *Limonius* spp. group. Sample representatives of other species have been sent to Montana State University for species confirmation.

Figure 1. *Click beetle pupae (Coleptera: Elateridae). Photo by Arash Rashed.*

Figure 2. Limonius *spp. wireworm burrowing into the soil. Photo by Arash Rashed.*

This project is anticipated to lead to publishing a visual identification guide to the most common wireworm species as well as a species distribution map for ID. We will be presenting a series of workshops and talks designed to educate wheat and barley producers, county educators, and crop consultants about the pest and available management tools. As a part of our extension and outreach commitment, we are currently in the process of preparing an extension educational video.

Figure 3. *Wireworm chemical trials north of Ririe, ID. Photo by Arash Rashed*

Figure 4. *Wireworm damage in dryland wheat near Geneva, ID. Photo by Arash Rashed.*

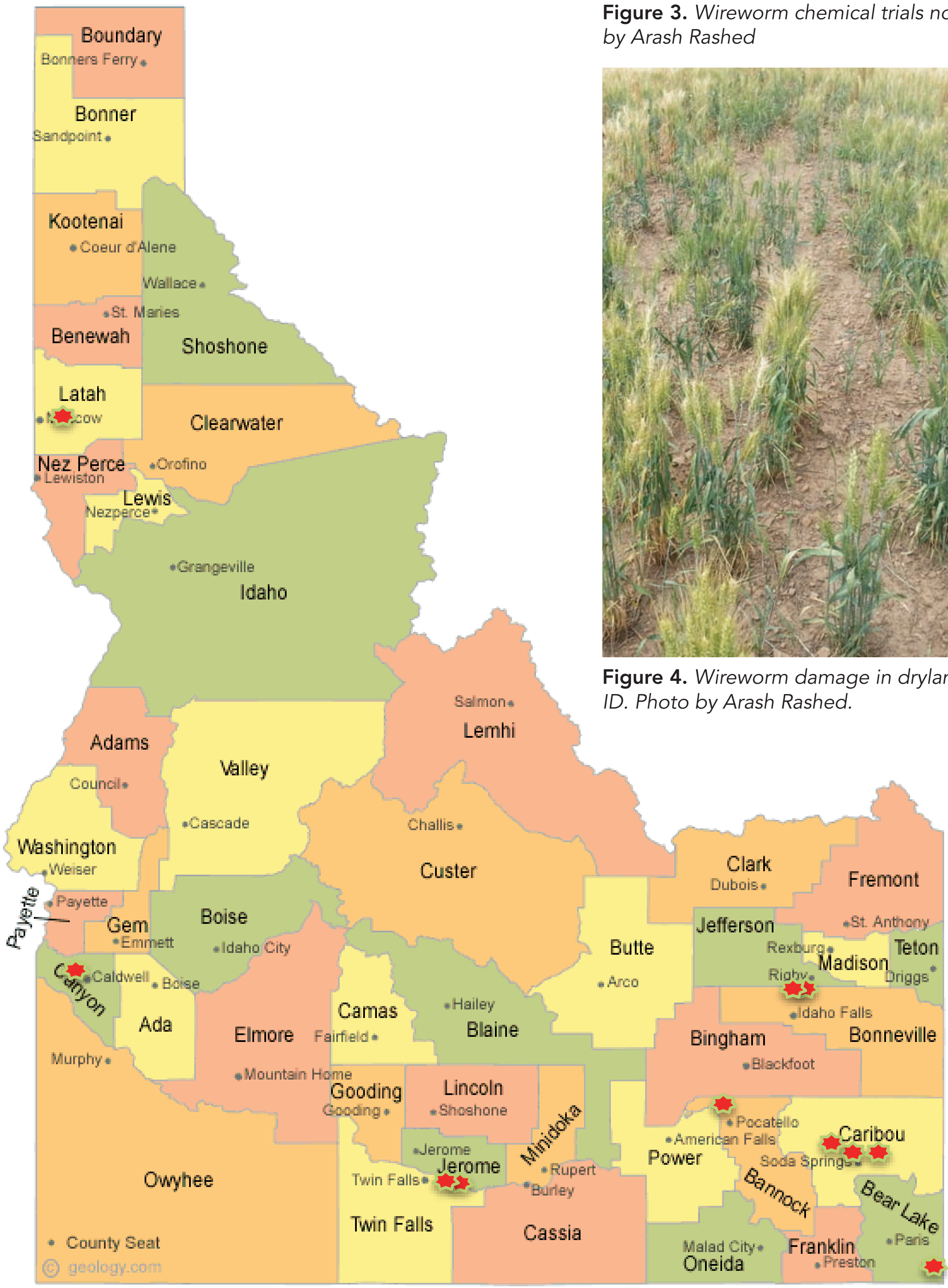


Figure 5. *Current wireworm survey locations in ID, locations indicated with red dots.*

Update on *Metopolophium festucae cerealium*, a new aphid in the Pacific Northwest

Sanford Eigenbrode (sanforde@uidaho.edu) UI, Brad Stokes UI, Seth Davis UI, and Ebrahim Sadeghi UI

In 2011, as part of REACCH sampling efforts, we discovered an aphid species new to North America. A putative specimen was recorded in OR in 1995, but it had not been observed since then. In 2011, as part of our regionwide sampling efforts, we detected the aphid, *Metopolophium festucae cerealium* (MFC) (Figure 1), in large numbers at dozens of sites. MFC continues to be abundant throughout the REACCH region, based on our samples from 2014. Although its average numbers per sweep net sample have declined relative to 2013, MFC is still abundant, constituting more than half of all aphids sampled. On some of its host plants, MFC can cause reddish staining around feeding sites, a type of injury that most other aphids in our region do not cause (Figure 2). The aphid is difficult to identify because it looks similar to the rose grass aphid, which can also be abundant in our region. When both are in their winged form, MFC has broken bars on the abdomen, which are absent on the rose grass aphid. In the more common wingless forms, MFC antennae get darker from base to tip, while the antennae on rose grass aphids are pale with black joints.

IMPACT

The appearance of a new aphid in Pacific Northwest wheat systems merits study to determine whether it will require different approaches to its management than those used for existing aphids immediately and into the future. The work under way will achieve this objective.

MFC is evidently native to Great Britain, and little is known about its ecology and potential as a pest here in the Pacific Northwest (PNW). As part of REACCH, we have established a laboratory colony to allow us to conduct experiments to learn more about its biology. In a multiple-choice experiment, MFC aphids prefer to settle on wheat and avoid corn, but they also will settle on barley, oat, and several grasses native to the PNW (Figure 3a). When confined on these plants, MFC reproduction is high on wheat and barley, intermediate on oat and blue wild rye, and poor on Idaho fescue, rough fescue, and blue bunch wheatgrass. It is unable to survive or reproduce on corn (Figure 3b). When allowed to develop unchecked on wheat plants, MFC readily kills the plants, as do other aphids that commonly infest wheat in our region: bird cherry-oat aphid, rose grass aphid, Russian wheat aphid, and English grain aphid. Experiments are needed to compare direct injury among aphid species to see if MFC causes more injury than other aphids.

Figure 1. Metopolophium festucae cerealium, *a newly arrived aphid affecting wheat in the Pacific Northwest. Photo by Brad Stokes.*

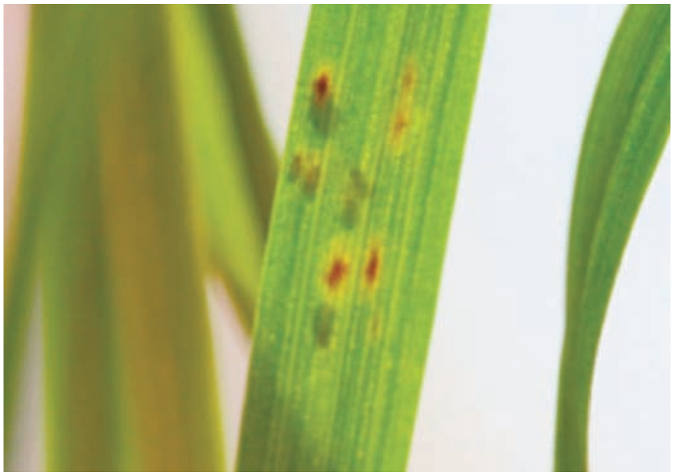


Figure 2. *Example of feeding injury caused by this aphid; on some hosts it can cause a red staining, as shown here. Photo by Brad Stokes.*

Whether MFC continues to be abundant in our region may depend upon responses of natural enemies. In extensive surveys conducted over four years, MFC constituted as much as 46% of all aphids captured (in 2012) but declined to just 9% in 2014 (Figure 4).

MFC and climate change

Is the presence of MFC in our region attributable to our warming climate? Unfortunately, this cannot be determined, since many other causes are possible, including a recent introduction of an aggressive population of this species, or adaptation to PNW con-

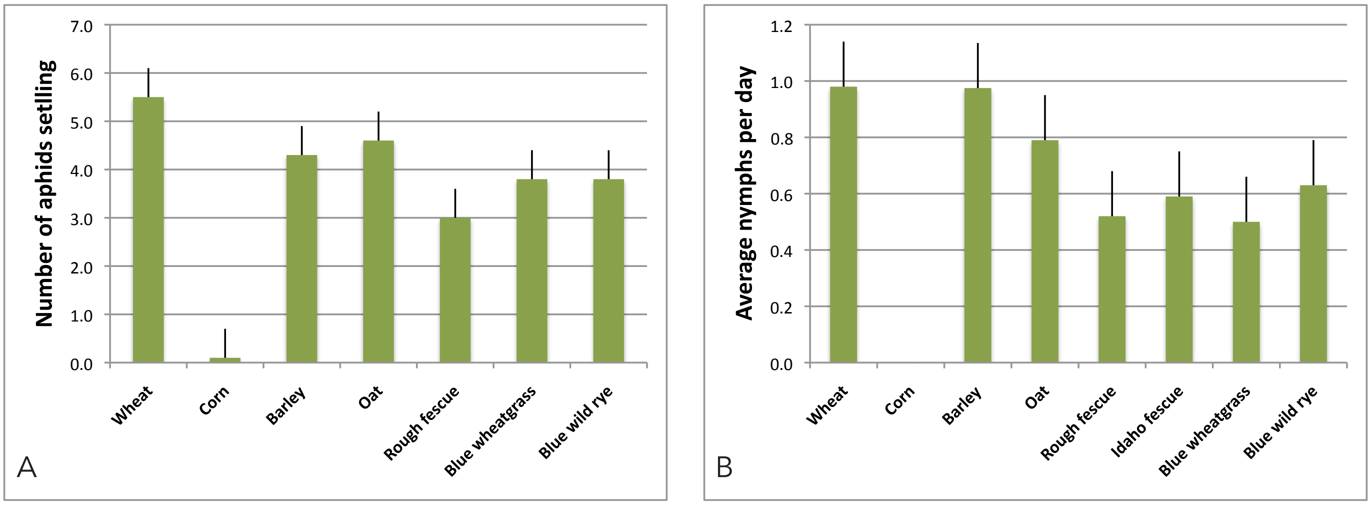


Figure 3. *Response of* Metopolophium festucae cerealium *to cultivated and native grasses of our region. (a) Number settling on each species when presented with all seven in a choice test. (b) Reproduction of the aphids when feeding on each of the grass species.*

ditions that have allowed it to become abundant. Nonetheless, we are investing resources in studying it, because it promises to be an important component of the pest complex in wheat during the future.

Next steps

Some questions concerning MFC are important to address in a timely manner. Whether MFC causes more direct injury per aphid than that caused by other aphids has not been established. The discoloration it causes suggests that it might be more injurious. Field trials conducted to measure its effects on wheat this past summer were unsuccessful due to heavy infestations from other aphids that obscured the effects of MFC alone. The trials will be conducted again in 2015. If MFC causes more injury than other aphids, more aggressive treatment might be indicated. It is also extremely important to determine if MFC can act as a vector of Barley yellow dwarf virus. In preliminary experiments, results have been too inconclusive to report here. It will be important to measure its capacity as a vector using different virus sources, virus isolates, and host plants. That work is under way as part of REACCH. This summer and last, we reared MFC specimens to determine if they were being attacked by parasitic wasps (natural enemies); two species of wasps were found, but they are rare. Continued monitoring for natural enemies is merited. Finally, we are broadly interested in assessing how aphids respond to climatic stresses such as heat and drought and how MFC interacts with other species, and we are conducting experiments to address these questions.

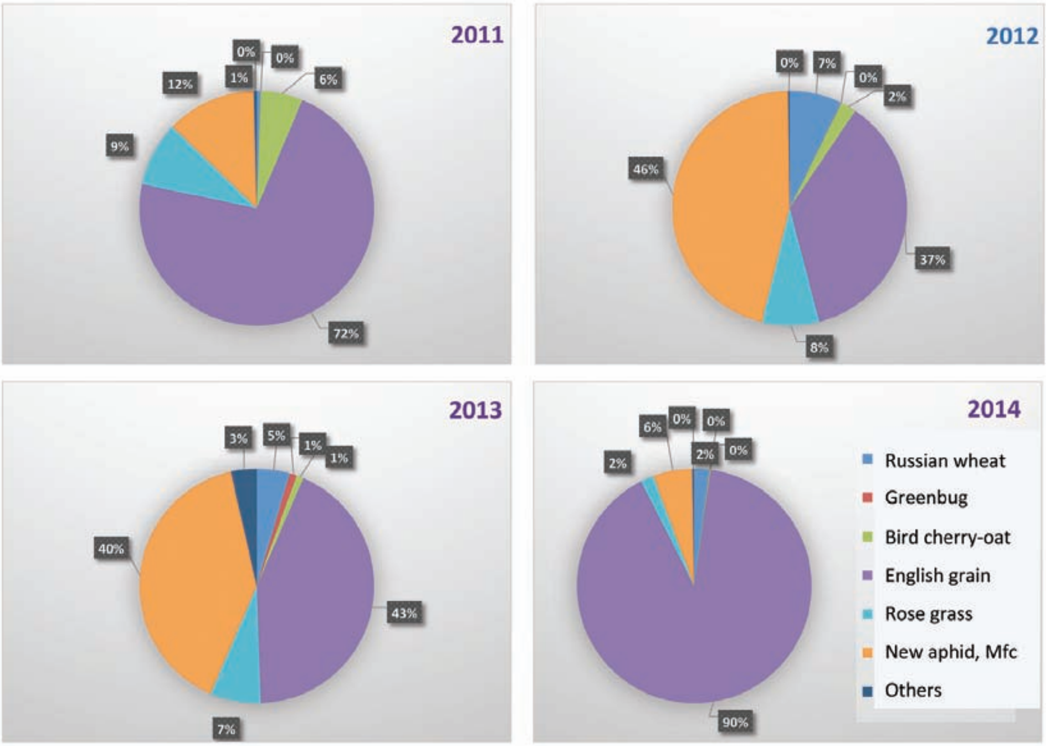


Figure 4. *Aphid community across the REACCH region, with percentages of individuals for each of the predominant species.* Metopolophium festucae cerealium *(MFC) was was most abundant in 2012 and second most abundant in 2013.*

Cereal aphids, climate variability, and change in the Pacific Northwest

Sanford Eigenbrode (sanforde@uidaho.edu) UI, Seth Davis UI, and Brad Stokes, UI

Like many insects, aphids respond to weather patterns and longer-term trends in winter and summer temperatures, precipitation, and wind patterns. The ongoing warming in the Pacific Northwest (PNW), coupled with reduced precipitation in summer, potentially could change the aphid abundance and movement patterns in the region, influencing their potential as pests. Since aphids are one of the principal pest groups affecting wheat, we are taking several approaches to delineating how they have responded to the climates of our region and how they might do so in the future.

IMPACT

Aphids are consistent pests across the REACCH region, and many producers report observing and treating for them. Climate variability and change affect the flight patterns and abundance of aphids. Baselines and trends in aphid densities can help growers anticipate continued risks associated with these insects as climates change.

First, we have employed an extensive record of aphids captured in suction traps in our region to examine annual fluctuations in the key aphid species over a 20-year period, during which the region's climate has also warmed slightly. We focused for this work on bird cherry-oat aphid, rose grass aphid, and Russian wheat aphid (Figures 1a through 1c). Second, we are continuing to monitor aphid flights using pan traps at several sites. Third, we have been monitoring aphids by sampling with sweep nets each summer at field sites across our region that differ markedly in climate (annual accumulations of heat units and precipitation) to determine if there are trends related to these climatic factors and land use. These efforts give us a better understanding of the current biology and ecology of these pests as a basis for making projections and improving their management.

Historical patterns from suction traps

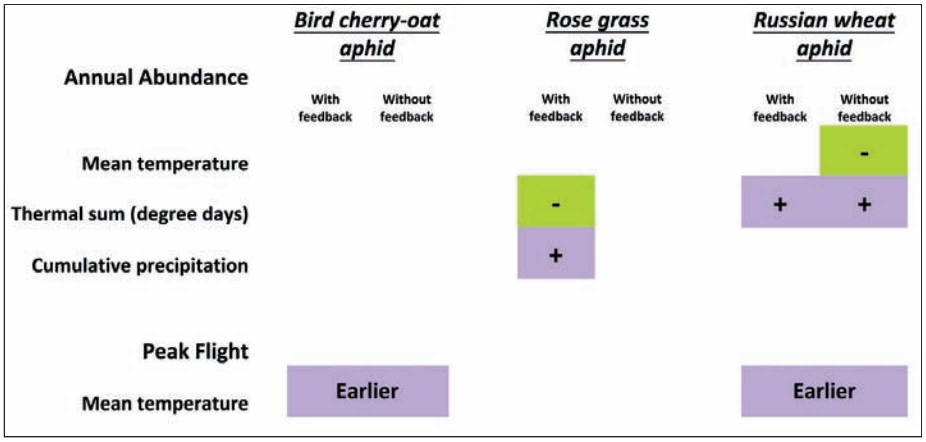
In the early 1980s, a network of 28 trapping locations was established in cereal grain production regions throughout the PNW and inland PNW. At each location, a suction trap was installed to sample populations of migrating aerial insects. These were operated for over 20 years, and the aphids captured each week were identified. With historic downscaled climate data, we have been able to relate capture records to weather patterns and trends. This information has allowed us to investigate how intrinsic and extrinsic climatic factors influence year-to-year variation in aerial densities of these aphid species.

In summary, we found that the population dynamics of all three aphid species showed evidence of feedbacks. That is, years with high numbers of trapped aphids were regularly followed by years with low aphid numbers. This indicates density-dependent mortality to aphids, whether from natural enemies, competition for winter hosts, or both. In addition, we detected changes in each of the species associated with climate trends (Figure 2). Interestingly, each species responded differently to climate. This illustrates the important point that different insect species, even very similar ones, respond differently to climate.

Pan trap sampling

Aphids collected in pan traps across the region can reveal arrival patterns that can help assess risks from these aphids during crop development, with the potential to discern patterns related to weather and trends. Figure 3 provides data for three years for two of the seven sites, Pendleton, OR, and Pullman, WA, and two aphid species, bird cherry-oat aphid (Figure 1a) and English grain aphid (Figure 1d). This example illustrates the continuing regionwide alternation between years in which aphids are abundant (2012) and years in which they are less abundant (2011 and 2013). It also illustrates differences in flight phenology between Pendleton (in Douglas

Figure 1. *The four predominant aphids in historic suction trap records. (a) bird cherry-oat aphid, (b) rose grass aphid, (c) Russian wheat aphid, (d) English grain aphid . Photos by (a) D. Schotzko, (b) Lancaster Univ. (c) D. Schotzko, and (d) Brad Stokes.*



	Bird cherry-oat aphid		Rose grass aphid		Russian wheat aphid	
Annual Abundance	With feedback	Without feedback	With feedback	Without feedback	With feedback	Without feedback
Mean temperature						-
Thermal sum (degree days)			-		+	+
Cumulative precipitation			+			
Peak Flight						
Mean temperature	Earlier				Earlier	

Figure 2. *Summary of responses of bird cherry-oat aphid, rose grass aphid, and Russian wheat aphid to temperature and precipitation over a 20-year period in the PNW. "With feedback" means that the data analysis included the interannual feedbacks from the effects of natural enemies or competition. "Without feedback" means that the feedback was excluded. In either case, the effects of climatic variables are shown if detected. The upper section refers to annual abundance—total aphids captured. The lower section refers to the estimated peak flight observed during each year.*

Zone 4), where bird cherry-oat aphid flights peak late in the season, and Pullman (in Douglas Zone 2), where midseason flights are more evident. The late-season flights of bird cherry-oat aphid are important, since these aphids are the primary vectors of *Barley yellow dwarf virus–padi-avenae* virus, the principal viral pathogen of wheat. Their late-fall flights can bring the virus into emerging fall-planted wheat.

Aphid communities

More than 10 species of aphids, including one species new to our region (see "Update on Metopolophium festucae cerealium, a new aphid in the PNW" pages 48-49), were encountered in sweep net samples taken near booting stage at 40 farms and several other research plot sites throughout the region each year for four years. Total aphid populations throughout the region have varied among sites; total aphids sampled were 4,213, 4,343, 3,584, and 7,043 in years 2011 to 2014, respectively. Since the sites we have sampled differ considerably in terms of climate (accumulating 400 growing degree days as early as mid-May or as late as early July), we compared these sites as possible surrogates for differing climates. Some of the patterns evident in these data include (1) a prevalence of Russian wheat aphid only in the warmer regions of northern OR and southern WA, (2) differences in the responses of each aphid species to climatic factors such as temperature, (3) fluctuating abundance between years, consistent with the feedbacks that are evident in suction and pan traps data. Ongoing analyses are relating the four years of aphid data with cropping systems and other land uses on the landscapes.

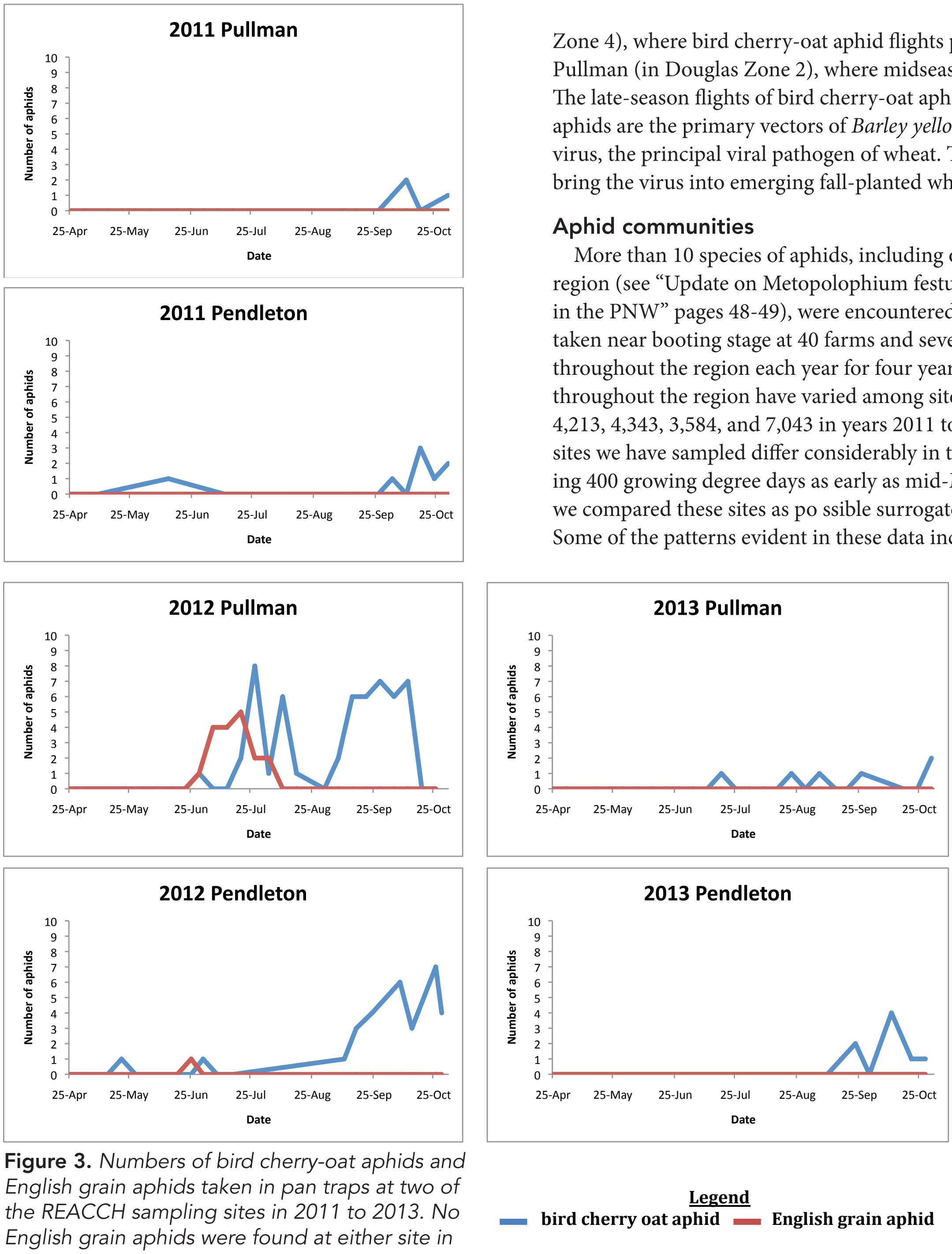


Figure 3. *Numbers of bird cherry-oat aphids and English grain aphids taken in pan traps at two of the REACCH sampling sites in 2011 to 2013. No English grain aphids were found at either site in 2011.*

Influence of climate and disturbance on the distribution and management of Italian ryegrass and mayweed chamomile in the Pacific Northwest

Nevin Lawrence (nevin.lawrence@email.wsu.edu) WSU, Leigh Bernacchi UI, J. D. Wulfhorst UI, and Ian Burke WSU

Italian ryegrass (*Lolium multiflorum* L.) and mayweed chamomile (*Anthemis cotula* L.) are two well-adapted weed species common in the Pacific Northwest (PNW) small-grain production region. Both species are summer annuals, with emergence occurring in the spring. While mayweed chamomile emergence occurs at the start of the spring growing season, Italian ryegrass can continue to emerge throughout the spring and summer if adequate soil moisture is available. Italian ryegrass and mayweed chamomile are pernicious competitors with crops and can severely reduce yield. An increased use of conservation tillage practices in the PNW has favored both weed species, as management now relies almost exclusively on herbicides. Mayweed chamomile control, particularly in pulse crops, requires well-timed herbicide applications and competitive stand establishment, as there are no effective postemergence herbicides. Italian ryegrass is considered one of the worst weeds globally in the context of herbicide resistance and has become resistant to several commonly used herbicides in the PNW. Italian ryegrass and mayweed chamomile are currently major pests in the PNW, and projected changes in climate over the next several decades may lead to expanded ranges for both species. However, little is known about the relationship among climate, management, and distribution of the two species.

IMPACT

We established baseline distribution of two weed species and the relationship between producer practices and their perception of control, including tillage. Knowledge of location and grower perceptions of their ability to control pests allow scientists to assess risk and pursue critical research questions.

To begin to gain an understanding of these relationships, we conducted a producer survey that asked growers, in part, to identify observation and control of species. In November 2012 to March 2013, the Social Science Research Unit of the University of Idaho administered a mail survey of agricultural producers in counties of the REACCH region in the inland PNW. The sample, which was drawn from the National Agricultural Statistics Service (NASS), consisted of 2,000 producers who grew more than 50 acres of wheat in 2011, by county. We employed the full Dillman

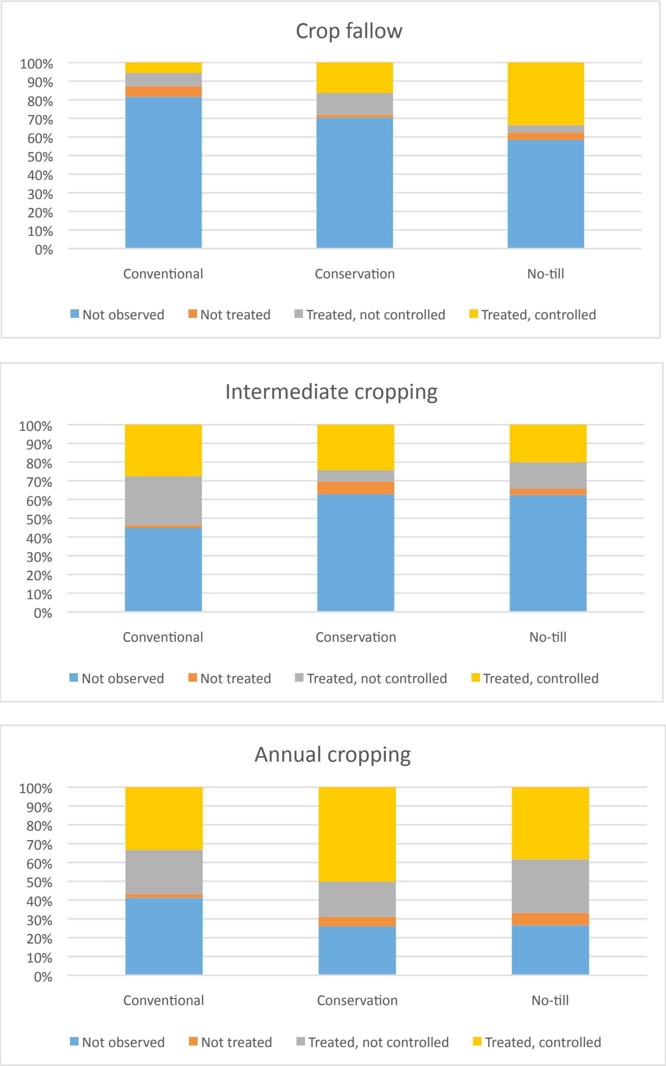


Figure 1. *Distribution and control of Italian ryegrass by tillage practice and cropping system (wheat-fallow, intermediate, and annual cropping). We used agroecological zone designations based on the 2012 Cropland Data Layer to describe the cropping system, and we used the producer survey to describe the distribution of species and tillage practices (conventional, conservation, and no-till). Producers are most likely to be affected by Italian ryegrass in the annual cropping zone.*

Figure 2. *Distribution and control of mayweed chamomile by tillage practice and cropping system. This weed is least likely to be controlled in the annual cropping and intermediate cropping zones. While tillage does not appear to affect control in annual cropping, more tillage is associated with less control in intermediate cropping systems.*

method, including four mailings and a postcard. The survey asked about perceptions of climate change, management practices, and demographics, and included maps on which to mark all parcels farmed and indicate the largest parcel. We used the largest parcel to specifically locate pests. We received 900 completed and eligible surveys, 4 undeliverable surveys, and 38 ineligible recipients, resulting in an overall response rate of 45%. The majority of respondents completed the mapping data with accuracy (n= 700, or 35%). The respondents identified multiple field sites, and for each site they were asked which of the two weeds affected their largest parcel and the degree to which they were controlled.

The observation of Italian ryegrass by cropping system (Figure 1) is likely a result of increased annual precipitation. Seventy percent of respondents from the crop-fallow production system did not observe Italian ryegrass, whereas 57% and 31% of respondents from the transition and annual cropping systems did not observe Italian ryegrass. A similar trend was observed with mayweed chamomile (Figure 2). In the crop-fallow production system (Figure 3), Italian ryegrass was observed more often in areas where no-till was used. The presence of Italian ryegrass in the no-till areas of the crop-fallow production systems may be a consequence of greater soil moisture retention or a more stable seed bed. The observation of Italian ryegrass in the transition and annual cropping systems was not as variable by tillage practices as in the crop-fallow system; however, control of Italian ryegrass was variable by tillage practices. Respondents from transition and annual cropping system who used conservation tillage rather than conventional tillage or no-till practices reported greater control of Italian ryegrass.

Mayweed chamomile is much less common in the crop-fallow production system, likely due to moisture. In the transition cropping zone, mayweed chamomile is more common in tillage systems, and also more difficult to control. The opposite is true in the annual cropping system zone, where mayweed is less commonly observed in systems that use tillage. No-till and conventional tillage practices differ considerably in the reliance on not only tillage but also herbicides. The greater control of Italian ryegrass observed when conservation tillage practices were used may reflect increased flexibility in tillage and herbicide use, allowing growers to better adapt their practices for difficult-to-control weeds. Finally, it appears that Italian ryegrass and mayweed chamomile are useful species as climate indicators, and that grower surveys can be useful tools for assessing, indirectly, climate effects on indicator species such as these two weeds.

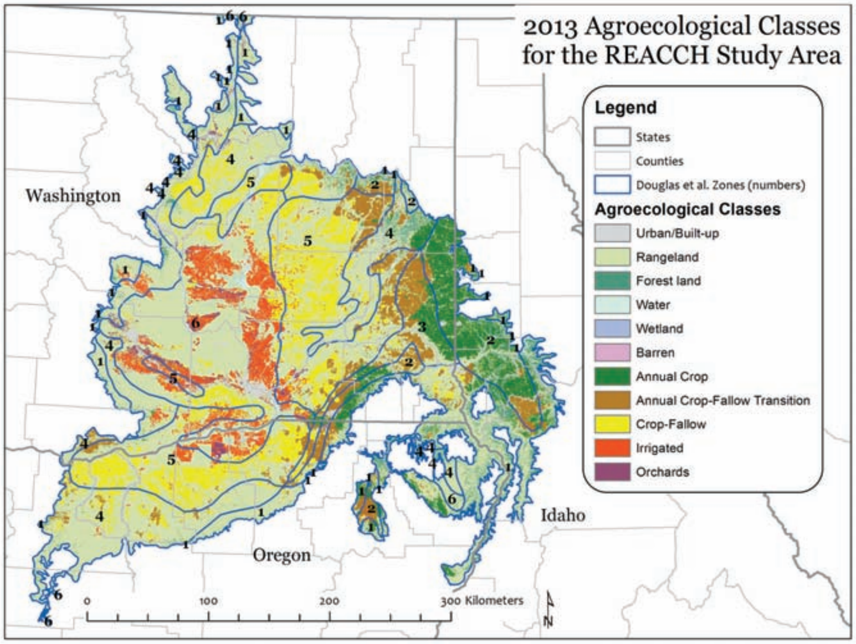


Figure 3. *Distribution of annual, transition, and crop-fallow cropping systems in the PNW. Map courtesy of Rick Rupp and Dave Huggins.*

Climate, management, and soil health

Jason Morrow (jason.morrow@wsu.edu) WSU and Dave Huggins USDA-ARS

Soil health has been discussed among scientists in analytical terms at least as far back as the Dust Bowl era, and most assuredly by farmers in descriptive terms since the advent of agriculture. A uniting theme of modern definitions of soil health is its capacity to provide essential ecosystem services at present and into the future. Consequently, soil health is an important concept for quantifying soil regeneration or degradation due to historic and current land management practices, as well as a critical factor in building resiliency in an era facing an uncertain future climate. Soil organic matter (SOM) is often identified as one of the most crucial properties of soil and therefore is an important attribute of soil health.

IMPACT

Future climate scenarios indicate potential threats to soil health. Improved understanding of soil health monitoring appropriate for the inland PNW can help guide management decisions aimed at improving soil health, thereby bolstering the region's agricultural resiliency as the climate changes.

SOM is made up of a continuum of dead and decaying material ranging from fresh plant residue to soil humus, which can persist in the soil profile for thousands of years. While several models exist that attempt to capture the complexity of this continuum, a two-pool SOM model is the simplest, consisting of a labile or more transient pool and a recalcitrant or more stable pool. These two SOM pools are associated with distinct soil properties and processes: the labile pool provides energy to the soil food web, which in turn drives nutrient cycling, aggregation, and micronutrient chelation, and the recalcitrant pool contributes to cation-exchange capacity, water-holding capacity, and soil structure. In accordance with their nature, labile SOM is typically associated with rapid changes resulting from management or weather fluctuations, while recalcitrant SOM changes more slowly in response to these factors. Across the REACCH study area, we have collected both labile and recalcitrant SOM data and identified how mean annual temperature (MAT) and mean annual precipitation (MAP), as well as both tillage and cropping intensity, influence labile and recalcitrant SOM pools. An analysis of these data will not only help inform present and future efforts to monitor soil health in the REACCH study area, but will also help guide management decisions aimed at improving soil health and thus can bolster the region's agricultural resiliency under future changes in climate.

In water-limited regions such as the inland Pacific Northwest (PNW), rainfall drives biomass production and in turn organic inputs to the soil, while SOM decomposition is influenced by temperature, precipitation, and other soil factors. This interplay of temperature and precipitation in SOM dynamics is evident across four dryland sites in the REACCH study area (Table 1). Across these sites, soil organic carbon and total nitrogen, important proxy measures of SOM, increase with increasing MAP and decreasing MAT (Figure 1). These data indicate that an increase in the MAT/MAP ratio would result in degradation of SOM across the region. For the inland PNW, climate models predict a 3° to 4°F rise in MAT by 2050 and a 4° to 6.5°F rise in MAT by 2100 and, correspondingly, a 5% to 15% rise in MAP by the middle and latter part of the 21st century. These scenarios represent an increase in the MAT/MAP ratio and subsequently a potential decline in SOM from present-day levels (Figure 1). They do not, however, take into account the uncertainty surrounding microbial response to future climate scenarios that will ultimately play an important role in future SOM levels. Nonetheless, management decisions will remain an important consideration in combating this potential decline in SOM.

Two management decisions that influence SOM levels and soil health are cropping intensification and tillage. Reducing the frequency of fallow increases plant residue inputs to soil and subsequently has the potential to increase SOM and improve soil health. A reduction in tillage intensity or adoption of no-tillage can enhance aggregation, improve soil structure, and subse-

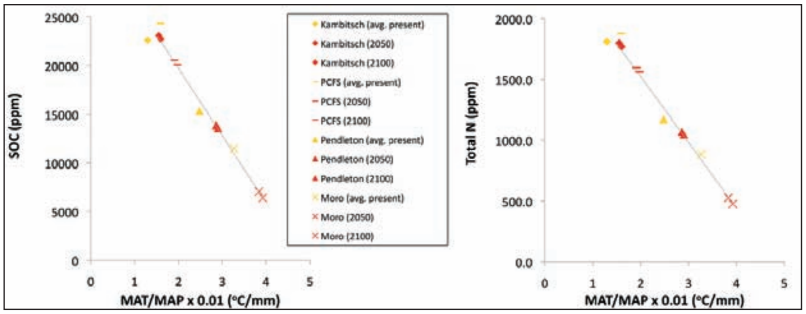


Figure 1. *Soil organic carbon (SOC) and total nitrogen (N) levels and their relationship to mean average temperature (MAT)/mean average precipitation (MAP) × 0.01 at present and under future climate scenarios for 2050 and 2100 across four dryland sites.*

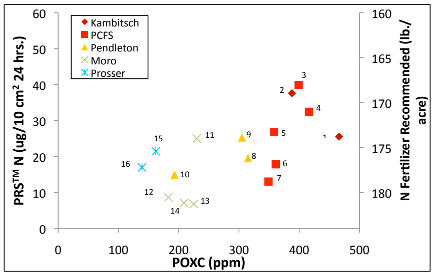


Figure 2. *Permanganate oxidizable carbon (POXC) with PRS nitrogen and corresponding recommended fertilizer application across five study sites and multiple treatments (numbers refer to treatment numbers in Table 1).*

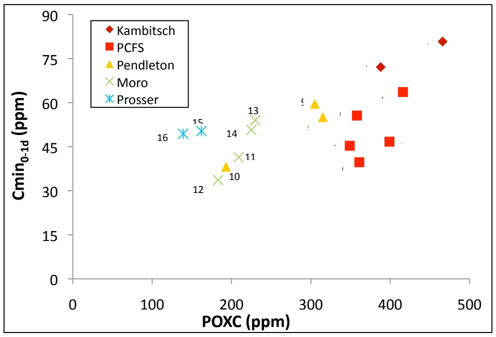


Figure 3. *Permanganate oxidizable carbon (POXC) with one-day carbon mineralization (C_{min}) across five study sites and multiple treatments (numbers refer to Table 1).*

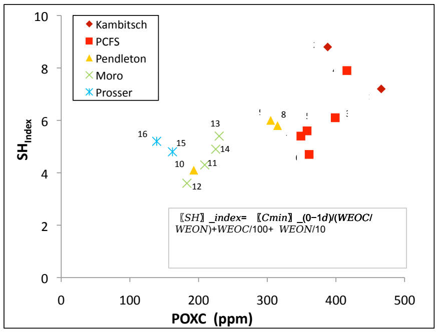


Figure 4. *Permanganate oxidizable carbon (POXC) with soil health index (SH_{index}) across five study sites and multiple treatments (numbers refer to treatment numbers in Table 1; WEOC and WEON refer to water-extractable carbon and nitrogen).*

quently protect SOM from microbial attack. Based on our analysis and review of multiple measures of SOM, we have selected four measures that are easily obtained and, when strategically coupled, are sensitive to climate and management practices, both important criteria for soil health monitoring. These measures are (1) permanganate oxidizable carbon (POXC); (2) one-day PRS™ nitrogen (plant root simulator; Western Ag Innovations, Saskatoon, Canada); (3) one-day carbon mineralization (C_{min}); and (4) a soil health index (SH_{index}) developed by the U.S. Department of Agriculture Agricultural Research Service (USDA-ARS) consisting of labile measures of SOM.

Across five study sites in the REACCH region (Table 1), POXC displayed sensitivity to both acid hydrolyzable carbon (r = 0.90) and nitrogen (r = 0.90), and acid non-hydrolyzable carbon (r = 0.84) and nitrogen (r = 0.80), providing evidence that it is a sensitive indicator of stabilized SOM. The other three measures of SOM capture a portion of the more labile SOM pool and, coupled with POXC, provide an inclusive method for monitoring both stable and labile SOM. POXC coupled with PRS™ nitrogen captures stabilized SOM along with plant-available nitrogen used to inform fertilizer applications (Figure 2). This method of soil health monitoring demonstrates the importance of nitrogen mineralization and emphasizes efficient use of fertilizer. POXC coupled with one-day C_{min} captures the microbial activity driving nutrient cycling along with stabilized SOM (Figure 3). Last, POXC coupled with SH_{index} captures the importance of the carbon-to-nitrogen (C/N) ratio in nutrient cycling (Figure 4). This method is also helpful in guiding cover crop choices to achieve a desired C/N ratio for improved efficiency of nutrient cycling. Ultimately, management goals should provide the basis for selecting methods of soil health monitoring.

Table 1. *Mean annual precipitation, temperature, and four measures of soil organic matter (SOM) across five study sites.*

Site	MAP[ŧ] (inches)	MAT[ŧ] (°F)	Treatment[†]	(parts per million)	(ug 10 cm^{-2} 24 hrs^{-1})	(parts per million)	SH$_{Index}$[§]
Kambitsch	26	47	1) WW/SB/SL – NT	466 a (8)	25.6 (55)	80.8 (16)	7.2 (19)
			2) WW/SB/SL – Till	388 b (6)	37.63 (44)	72.1 (23)	8.8 (27)
Palouse Conservation Field Station	21	47	3) WW/SL/SW – NT	399 (11)	39.9 (45)	46.7 (9)	6.1 (22)
			4) WW/SB/SW – NT	416 (9)	32.5 (50)	63.6 (53)	7.9 (37)
			5) Alf/SC/SL (organic) – NT	358 (11)	26.8 (30)	55.6 (50)	5.6 (33)
			6) Perennial tall wheat grass	361 (8)	17.9 (32)	39.7 (8)	4.7 (7)
			7) Native/CRP grass	349 (10)	13.1 (35)	45.3 (29)	5.4 (16)
Pendleton	16	51	8) WW/ NT Fallow – NT	315 a (10)	19.6 (35)	55.1 a (3)	5.8 a (4)
			9) WW/Pea – NT	305 a (11)	25.3 (26)	59.6 a (12)	6.0 a (7)
			10) WW/Fallow – Till	193 b (48)	15.0 (40)	38.2 b (7)	4.1 b (8)
Moro	11	49	11) WW/WP – NT	230 a (4)	25.0 a (12)	54.0 (24)	5.4 (15)
			12) WW/NT Fallow – NT	209 b (10)	11.3 b (13)	41.4 (34)	4.3 (17)
			13) WW/SB/NT Fallow – NT	225 ab (3)	6.9 b (51)	50.7 (42)	4.9 (28)
			14) WW/Fallow – Till	183 c (5)	8.7 b (45)	33.6 (16)	3.6 (13)
Prosser (irrigated)	8	52	15) WW/Sw. cn./Potato – NT	162 (10)	21.5 (35)	50.3 (14)	4.8 (32)
			16) WW/Sw. cn./Potato – Till	139 (28)	18.8 (9)	49.4 (18)	5.2 (13)

* Significant differences within sites at $p < 0.10$ and indicated by different letters; number in parentheses is coefficient of variation.

[ŧ] Based on closest weather station for the period 1955 to 2012.

[†] WW = winter wheat; SL = spring legume; SB = spring barley; SC = spring cereal; SW = spring wheat; WP = winter pea; Sw. cn. = sweet corn; Alf. = alfalfa; CRP = conservation reserve program; NT = no-till.

[§] POXC = permanganate oxidizable carbon; PRS $N_{0\text{-}1d}$ = N adsorbed to plant root simulator after 1 day; $Cmin_{0\text{-}1d}$ = cumulative 1-day carbon mineralization; SH_{index} = soil health index.

Performance criteria for evaluating site-specific nitrogen management

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Improving the efficiency with which nitrogen fertilizers are used in modern cropping systems can improve environmental quality while also providing economic benefit to agricultural producers. Maintaining high crop yields with fewer nitrogen fertilizer inputs is the essence of improved nitrogen use efficiency (NUE). Another option to improve NUE would be to obtain yield increases with the same amount of nitrogen fertilizer input. Given the high spatial and temporal variability in soil properties and crop productivity in the Palouse region, we are often interested in both—that is, in developing systems that can produce the same amount of grain with less nitrogen fertilizer as well as adopting management strategies that increase yield with the same amount of nitrogen fertilizer inputs. Site-specific nitrogen fertilizer management (otherwise known as variable rate) is considered a meaningful strategy to increase NUE.

IMPACT

The large range in nitrogen use efficiency observed in previous and current research at the Cook Agronomy Farm underscores the need to develop site-specific management strategies. Targeting site-specific management strategies to increase nitrogen use efficiency is important for reducing the costs of nitrogen fertilizer inputs and for minimizing the entry of nitrogen into unintended parts of the environment.

Managing the year-to-year and within-field variability across Palouse landscapes continues to generate interest in variable rather than uniform rates of crop production inputs such as nitrogen fertilizer. However, if agricultural producers are to adopt site-specific management decisions, they require accurate information on the variability in soil properties, coupled with knowledge of crop response to this variability. More importantly, agricultural producers will need decision support tools to evaluate whether site-specific management strategies allowed them to meet their production and NUE goals. Our aim for this research was to develop NUE-based performance classes while investigating the role of variable-rate nitrogen and seeding of soft white winter wheat for optimizing relationships between yield and NUE.

NUE is a measure of the amount of crop that is harvested divided by the amount of nitrogen supplied from soil and fertilizer sources (Table 1). The generally accepted NUE in current fertilizer guides for the region is 22 pounds of grain per pound of nitrogen supplied (Figure 1). We combined 605 data points from nitrogen fertilizer crossed with seeding-rate plot trials conducted across different landscape positions at the Cook Agronomy Farm, near Pullman, WA during the 2010, 2011 and 2012 soft white winter wheat harvest years. Over all plots and site years, the NUE ranged from 8 to 70 pounds of grain produced per pound of nitrogen supplied, with an average of 29 pounds grain per pound

Table 1. *Mean soft white winter wheat grain yield and select nitrogen use efficiency components by performance class for the 605 data points collected from 2010 to 2012 at the Cook Agronomy Farm near Pullman, WA.*

Nitrogen use efficiency component	Performance class			
	1	2	3	4
n (number of points)	311	102	82	110
Grain yield (Gw), bushels per acre	91	71	94	69
Grain protein, %	8.8	8.2	10.5	10.7
Aboveground plant nitrogen (Nt), pounds per acre	107	75	138	105
Nitrogen supply (Ns), pounds per acre	162	207	204	244
Harvest index, Gw/total biomass	0.45	0.43	0.42	0.37
Nitrogen harvest index, Ng/Nt	0.78	0.78	0.74	0.69
NUE, Gw/Ns	37	21	28	16
Unit nitrogen requirements, Ns/Gw	1.8	3.0	2.2	3.6
Nitrogen utilization efficiency, Gw/Nt	52	56	41	37
Nitrogen uptake efficiency, Nt/Ns	0.70	0.36	0.70	0.43
Total available water, inches	16	14	15	13

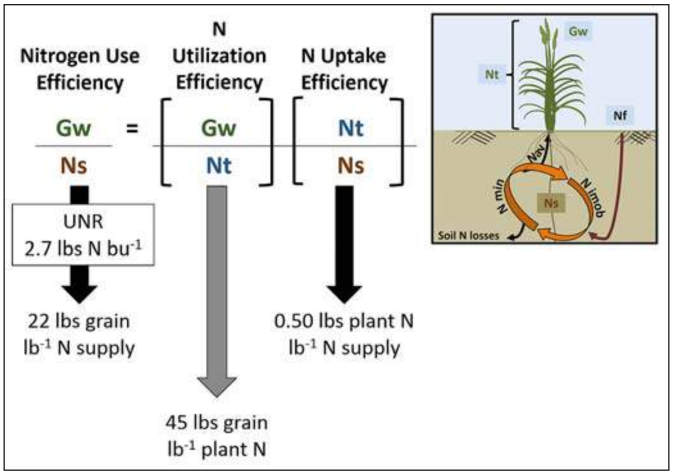
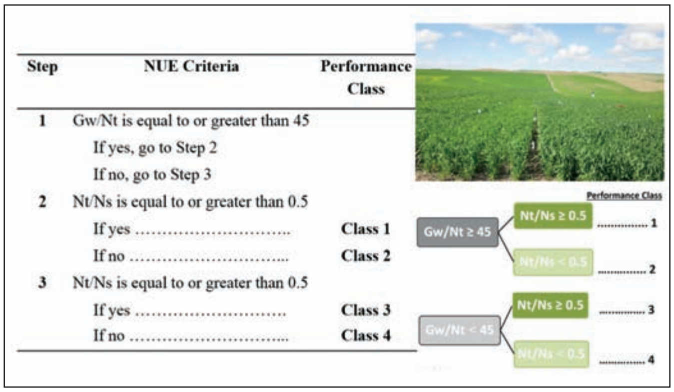


Figure 1. *Calculation of nitrogen use efficiency using soil- and plant-derived components and performance criteria established from regional soft white winter wheat fertilizer guide recommendations.*



Step	NUE Criteria	Performance Class
1	Gw/Nt is equal to or greater than 45	
	If yes, go to Step 2	
	If no, go to Step 3	
2	Nt/Ns is equal to or greater than 0.5	
	If yes	Class 1
	If no	Class 2
3	Nt/Ns is equal to or greater than 0.5	
	If yes	Class 3
	If no	Class 4

Figure 2. *Dichotomous key to classification of soft white winter wheat performance based on the nitrogen use efficiency components of nitrogen utilization efficiency (Gw/Nt) and nitrogen uptake efficiency (Nt/Ns).*

of nitrogen supply. This corresponds to a unit nitrogen requirement (UNR) range of 0.6 to 7.6 pounds of nitrogen supply per pound of grain yield (average of 2.4 pounds of nitrogen supply per pound of grain).

To evaluate and diagnose conditions contributing to NUE below fertilizer guide specifications, we partitioned NUE into several soil- and crop-based components or indices (see Table 1). NUE (Gw/Ns) was partitioned into nitrogen utilization efficiency (Gw/Nt) and nitrogen uptake efficiency (Nt/Ns) (Figure 1). We developed a dichotomous key to separate wheat performance into four classes based on nitrogen utilization efficiency (Gw/Nt) and nitrogen uptake efficiency (Nt/Ns), following the criteria of the regional soft white winter wheat fertilizer guides (Figure 1). Regional fertilizer guides estimate a UNR of 2.7 pounds of nitrogen per bushel of soft white winter wheat, and this value assumes a nitrogen uptake efficiency of at least 50%. Using these criteria, we calculated a nitrogen utilization efficiency value of greater than or equal to 45 pounds nitrogen per pound of grain as a performance goal. It should be noted that the NUE defined here is the inverse of the UNR.

Performance classes 1 and 2 are where wheat achieved a nitrogen utilization efficiency of 45 or greater (Figure 2). Performance classes 3 and 4 are conditions in which the nitrogen utilization efficiency goal of 45 was not achieved. Within the nitrogen utilization efficiency criteria, performance classes were further separated based on a nitrogen uptake efficiency criterion of 50%. Performance classes 1 and 3 are where nitrogen uptake efficiency is greater than or equal to 50%, and classes 2 and 4 are where nitrogen uptake efficiency is below 50%. Performance class 1 represents a situation in which soft white winter wheat crop and management strategies are well suited to the environmental conditions. In performance class 1, grain yields are high, with nitrogen utilization efficiency and nitrogen uptake efficiency goals achieved (Table 1). Performance class 1 was achieved in 311 out of 605 data observations, or approximately 50% of the time (Figure 3). Performance classes 2, 3, and 4 represent field or management situations in which site-specific management strategies might enhance NUE. We are continuing to use soil- and crop-based NUE components to diagnose environmental or management strategies contributing to low NUE. For example, low nitrogen utilization or uptake efficiency may be related to nitrogen loss (low nitrogen retention efficiency), over- or under-fertilization, a below-optimal plant population (nitrogen sink capacity), or moisture-stress-induced nitrogen deficiency (available water supplies). We will use this approach to develop decision support tools for evaluating how site-specific management strategies contribute to achieving yield, protein, NUE, and economic performance goals.

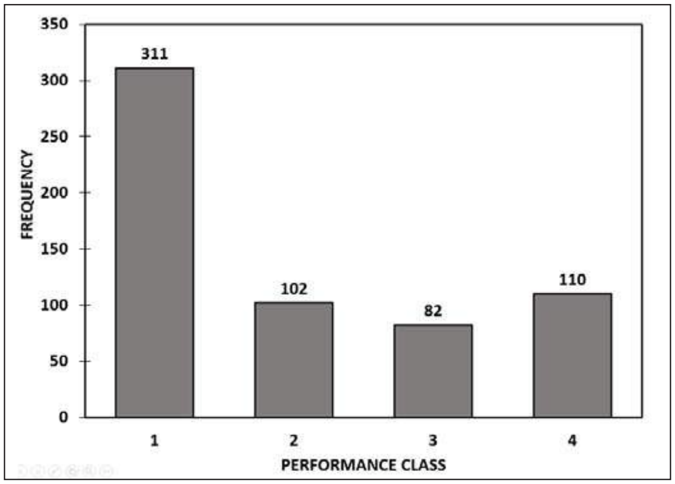


Figure 3. *Frequency of performance classes for the 605 data points collected during 2010, 2011, and 2012 soft white winter wheat nitrogen rate × seed rate plot trials at the Cook Agronomy Farm near Pullman, WA.*

Tabitha Brown sharing her research at a Cook Farm field day. Photo by Brad Stokes.

Reducing nitrate leaching through winter cover cropping

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Potatoes, wheat, and corn are commonly grown under irrigation in cropping sequences in the Columbia Basin. Irrigated cropping systems offer special potential for intensification, as they are not water limited. Intensification through cropping makes use of the solar energy in the fall and the spring, which would otherwise fall idle on the fallow ground. The additional biomass introduced into the crop sequence increases the overall soil organic matter acting as a sink for atmospheric carbon dioxide (CO_2). Cover crops can also be used to reduce nitrogen fertilizer loss and potentially replace the use of fumigants as a pest control. The roots of cover crops, active after the harvest of the main crop in the fall and before planting in the spring, retain nitrogen in the upper layers of the soil profile, recycling it for the next year and reducing the concern of nitrate (NO_3^-) leaching into ground water. Reducing tillage also has the potential to increase soil organic matter and reduce emissions of nitrous oxide (N_2O, a greenhouse gas) from the soil.

IMPACT

Cover cropping has the potential for on- and off-farm benefits. The research presented here demonstrates the ability of cover crops to recapture nitrogen as it moves through the soil profile, potentially reducing the required fertilizer rate and negative externalities, such as nitrate leaching into groundwater.

In this study, potatoes, wheat, and corn were grown in rotation under hand line irrigation at the Washington State University Prosser Irrigated Research Station. Cover crops and reduced tillage were implemented in the rotation. Mustard was grown as winter cover after the corn and before potatoes. Triticale was grown following wheat and preceding corn. Winter wheat was grown after potatoes, providing winter cover for the third winter. Reduced tillage consisted of no-tilling during the wheat and corn years of the rotation and minimal tillage during the potato season.

In the data presented here, we examined the ability of cover crops to take up NO_3^-. In our preliminary results, when we compare plots grown with a winter cover crop to fallow plots, all plots showed a decrease in soil NO_3^- in the first foot, but the total increase in NO_3^- lower in the profile was greater in the fallow plots than in the cover-cropped plots (Figures 1 and 2). The increase in NO_3^- deeper in the soil in fallow plots suggests that mustard and triticale would prove effective at reducing the leaching of NO_3^- through the soil profile over the winter.

Winter wheat followed by an overwintering triticale and fallow treatment showed a decrease of 14.9 pounds of NO_3^- per acre and 10.6 pounds of NO_3^- per acre in the top foot. At 2-, 3-, and 4-foot depths, the NO_3^- in the fallow plots increased by 3.7, 9.0, and 1.9 pounds per acre, respectively. In the plots with overwintering triticale, the NO_3^- in the 2nd, 3rd, and 4th feet changed a negligible amount, decreasing by 0.2 pound per acre in the 2nd foot and increasing by only 0.45 and 1.10 pounds per acre in the 3rd and 4th feet (Figure 1). At harvest, the triticale contained 18.2 pounds of nitrogen per acre.

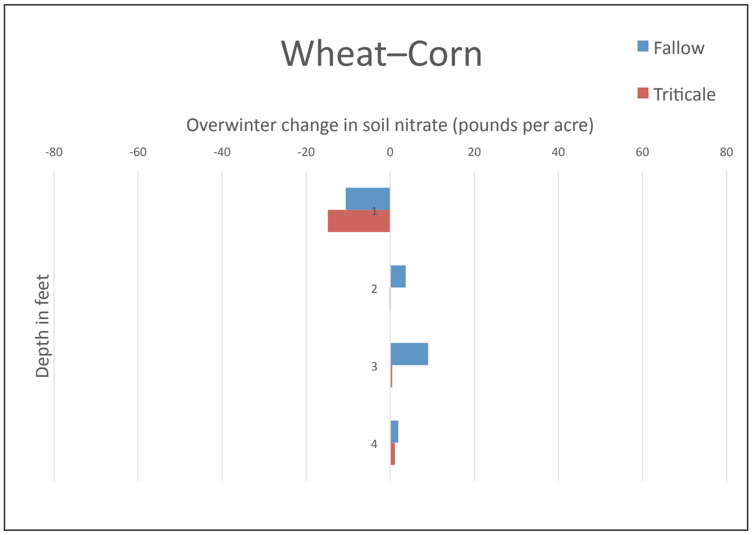

Figure 1. *Change in pounds of soil nitrate (NO_3^-) per acre at depths of 1 to 4 feet after in-season wheat and before corn, contrasting the cover crop (triticale) and the fallow.*

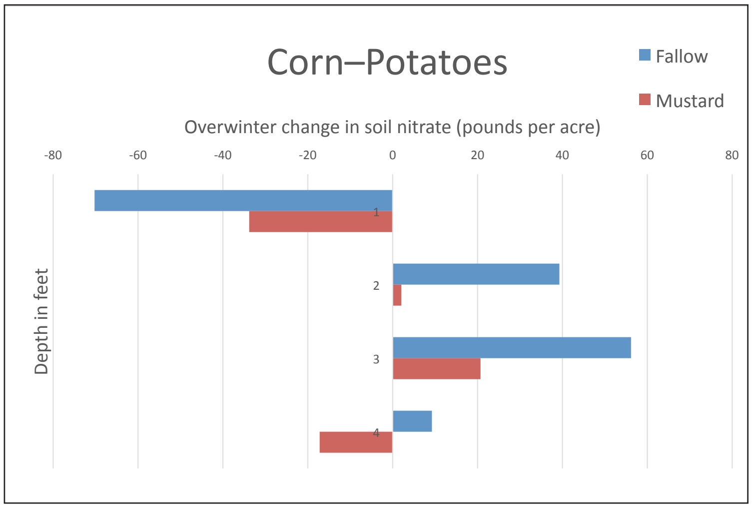

Figure 2. *Change in pounds of soil nitrate (NO_3^-) per acre at depths of 1 to 4 feet after in-season corn and before potatoes, contrasting the cover crop (mustard) and fallow.*

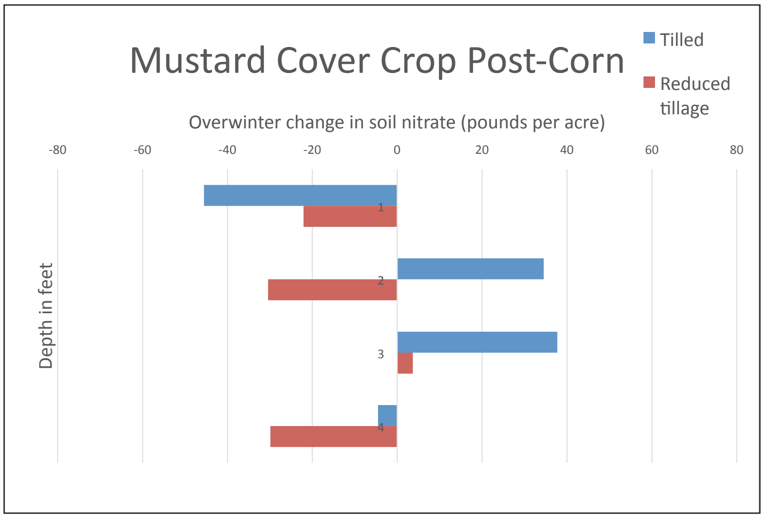

Figure 3. *Change in pounds of soil nitrate (NO_3^-) per acre at depths of 1 to 4 feet after in-season corn and before potatoes in plots with an overwinter cover crop of mustard and under contrasting tillage practices.*

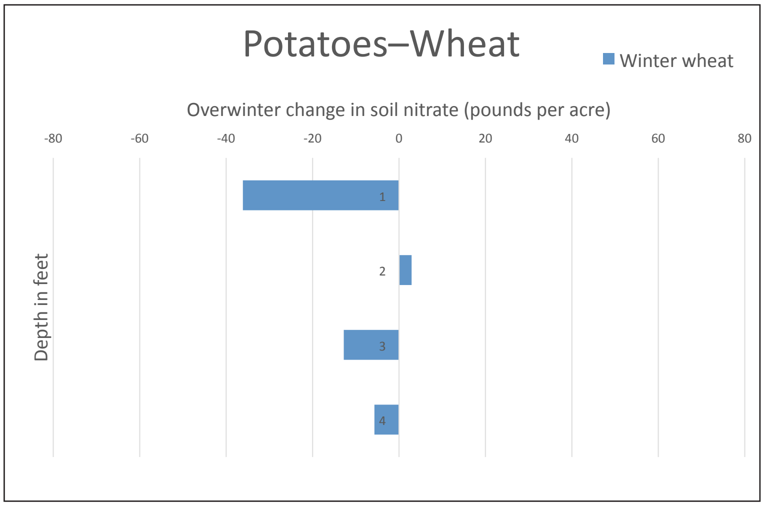

Figure 4. *Change in pounds of soil nitrate (NO_3^-)per acre at depths of 1 to 4 feet after in-season potatoes and during winter wheat.*

Wilke Farm cover crop trial. Photo by Diana Roberts.

Overwintering mustard following corn and preceding potatoes showed a similar result: a decrease in NO_3^- levels in the top foot by 33.8 pounds per acre, with a decrease in the top foot of fallow of 70.2 pounds per acre. The total NO_3^- at 2-, 3-, and 4-foot depths in the fallow increased by 39.3, 56.2, and 9.25 pounds per acre, respectively. In the plots covered with overwintering mustard, the 2- and 3-foot depths increased by 2.04 and 20.69 pounds per acre, respectively, while the 4-foot depth decreased by 17.2 pounds per acre (Figure 2). The mustard biomass tilled back in at springtime had a nitrogen yield of 56.3 pounds per acre. In the plots with overwintering mustard, it appears that reduced tillage may have compounded the reduction of NO_3^- in the soil profile. Plots with overwintering mustard and reduced tillage showed overwinter decreases in NO_3^- of more than 20 pounds per acre in the 1st, 2nd, and 4th feet, with only a small increase in the 3rd foot (3.67 pounds per acre). However, tilled plots showed increases in the 2nd and 3rd feet and a decrease in the 4th foot. Although the tilled plots with overwintering mustard showed an increase in the 2nd and 3rd feet, the increases in the corresponding fallow/tilled plots were still greater (Figure 3).

Isaac Madsen collects biomass samples of cover crops in Prosser, WA. Photo by Lauren Young.

In plots grown with potatoes and followed by winter wheat, overwinter levels of NO_3^- decreased at depths of 1, 3, and 4 feet by 36.1, 12.8, and 5.7 pounds per acre, respectively, and increased slightly in the 2nd foot by 2.9 pounds per acre (Figure 4).

In conclusion, a loss from the first foot and redistribution of NO_3^- in the 2nd and 3rd feet was the pattern in the fallow plots, while in the plots containing mustard and triticale the reduction in the 1st foot of the soil profile did not redistribute further down the profile. Results also indicate that there may be an interaction between the tillage system employed and the overwinter cover. Both cover cropping and reduced tillage are conservation practices that contribute to the buildup of soil organic matter, potentially increasing the sequestration of atmospheric CO_2. Cover cropping and reduced tillage also have on-farm benefits of mitigating erosion and nitrogen loss.

Nitrous oxide in the inland Pacific Northwest

Georgine Yorgey (yorgey@wsu.edu) and Chad Kruger WSU

For those interested in understanding farming's impact on climate change, nitrous oxide is an important piece of the picture. This is because nitrous oxide is a powerful greenhouse gas (298 times more powerful than carbon dioxide, over a 100-year time frame). And nitrous oxide from agricultural soils is a significant contributor to agriculture's direct greenhouse gas emissions, as estimated through inventories of such emissions. In all three Pacific Northwest (PNW) states (WA, OR, and ID), it has been estimated that nitrous oxide from soils accounts for 40% to 50% of direct greenhouse gas emissions from agriculture. However, these estimates rely on “default” assumptions about nitrous oxide emissions that were developed from global data—and a review of existing experimental data in the inland PNW suggests that these defaults may not be appropriate in our region.

IMPACT

A review of published season-long (or longer) nitrous oxide emissions values in the inland PNW suggests that emissions may be on the low side compared to other regions of the United States and world. If ongoing research confirms this, it suggests that any efforts to reduce nitrous oxide emissions through management should focus on strategies that offer strong co-benefits, such as raising yields or saving water.

Nitrous oxide emissions occur in agricultural soils (and also in nonagricultural soils) when microbes in the soil transform nitrogen from one form to another, specifically during the processes of nitrification and denitrification. However, more nitrous oxide is produced under some conditions than others—for example, when nitrogen is added to soils (as in most farming systems) and when oxygen in soils is limited (for example, when soils are saturated with water from rainfall or melting snow).

Most work on nitrous oxide in the PNW has been done since 2000, and there's not an overwhelming quantity of data. However, existing data suggest that emissions from most inland PNW croplands may be on the low side compared to other regions of the United States and world (Figure 1). The data in Figure 1 were collected as part of the ongoing webinar series on PNW Agriculture and Climate Change, supported by REACCH.

On the left is the Intergovernmental Panel on Climate Change (IPCC)'s “Tier 1 emissions factor,” indicating that in the absence of more specific data, it should be assumed that 1% of nitrogen applied as fertilizer is emitted as nitrous oxide. This number is based on a global review of nitrous oxide emissions data in agricultural systems. In recognition of the high amounts of variability in the data, they suggest an uncertainty range of 0.3% to 3% (shown in the graph with the error bars). Immediately to the right of the IPCC Tier 1 emissions factor are data from several conventional and no-till dryland cropping rotations in Bozeman, MT. The next two measurements are from dryland winter wheat in WA. At the far right are two measurements from irrigated systems, representing measurements in a sweet corn–sweet corn–potato rotation.

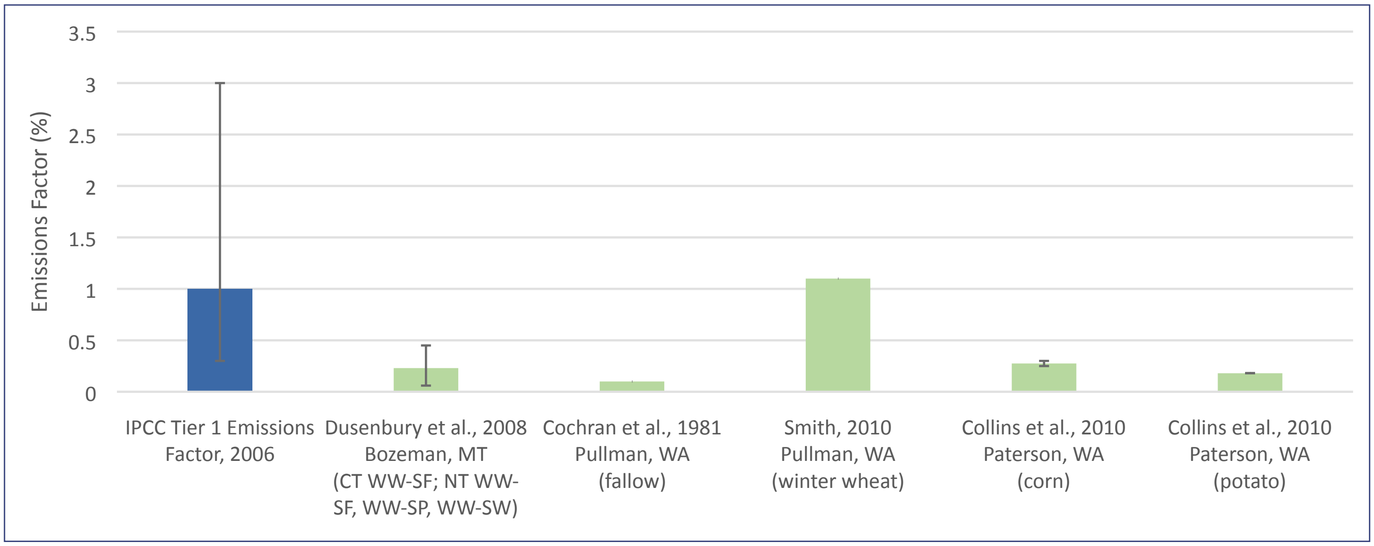

Figure 1. *Intergovernmental Panel on Climate Change (IPCC) Tier 1 emissions factor compared to existing published experimental data collected under field conditions in Montana and the inland PNW. Experimental measurements are for two years (Dusenbury et al. 2008), 41 days (Cochran et al. 1981), or growing season (Smith 2010 and Collins et al. 2010). Error bars on this graph represent uncertainty range (IPCC) and ranges across multiple crop rotations and nitrogen levels (for Dusenbury et al. 2008) or years (Collins et al. 2010). IPCC Tier 1 emissions factor is from DeKlein et al., 2006.*

Published modeling results also suggest that emissions are on the low side compared to IPCC estimates (Figure 2). For detailed explanation of both graphs, see the webinar "Nitrous Oxide Emissions in inland Pacific Northwest Cropping Systems" at csanr.wsu.edu/webinars/pnw-ag-and-climate-change/.

Ongoing work in the PNW, through the REACCH project, the Site-Specific Climate-Friendly Farming project, and others, will either confirm or refute this tentative conclusion. Methods being used include experimental efforts using sophisticated flux towers along with the chamber methods that are captured in the data described earlier, as well as modeling efforts. These multiple strategies are being used to try to overcome difficulties that result from the event-based and localized nature of nitrous oxide emissions, which makes it difficult to accurately capture field-level emissions.

The answers that we get will likely have implications for how we might mitigate nitrous oxide emissions in the inland PNW. If emissions are fairly low, one implication is that any efforts to reduce nitrous oxide emissions through management should focus on strategies that offer strong co-benefits, such as raising yields or saving water. This is because with lower overall emissions, any strategies that reduce greenhouse gas emissions will also have relatively smaller incentives (whether through carbon credits or some other structure), so strong co-benefits will likely be important for adoption.

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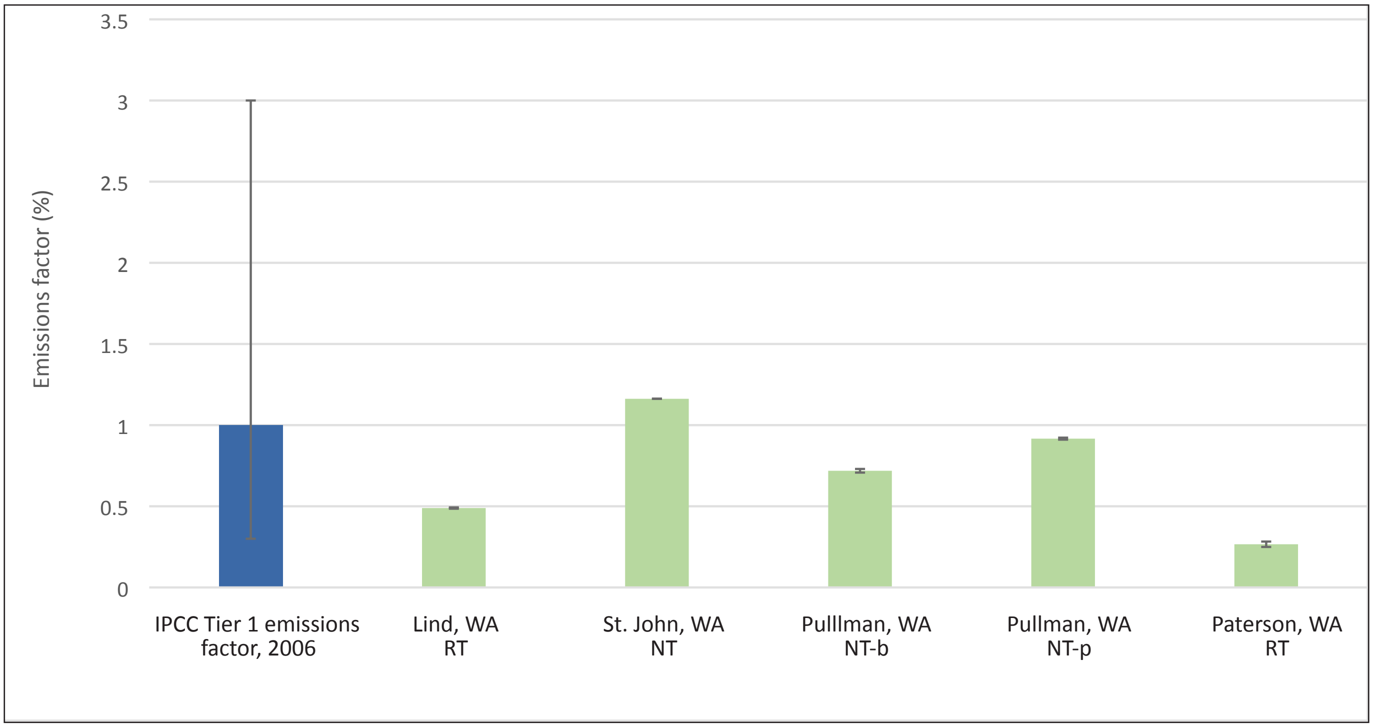

Figure 2. *Intergovernmental Panel on Climate Change (IPCC) Tier 1 emissions factor compared to published modeling results for the inland PNW. Modeling results are annual nitrous oxide emissions, averaged over 30 years, simulated by CropSyst and expressed as a percentage of applied nitrogen, for reduced tillage (RT) and no-till (NT) crop rotations at four locations in eastern WA. Pullman NT-b has barley in rotation; Pullman NT-p has peas in place of barley. Error bars for IPCC emissions factor represent uncertainty range. Error bars for CropSyst values represent range between low oxidation and high oxidation boundaries. The results summarized here are from De Klein et al. 2006 (IPCC data) and Stockle et al. 2012.*

Cropping system nitrogen use efficiency after 10 years of no-tillage

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Nitrogen use efficiency (NUE) calculated from a single growing season is often 40% or lower and likely underestimates cropping system NUE, as it does not include nitrogen still cycling within the soil. Therefore, evaluating NUE over multiple growing seasons, rather than a single growing season, may provide an improved assessment of NUE. Cropping system NUE may also vary spatially across heterogeneous landscapes and soils due to differences in crop performance and pathways of nitrogen loss or internal nitrogen storage within the soil.

IMPACT

A study of the effect of conversion from conventional tillage to no-tillage showed that soil profile nitrogen increased by 35 pounds per acre annually. Cropping system nitrogen use efficiency (NUE) was about two times greater than what is typical of a single crop. This occurred as applied fertilizer nitrogen promoted increases in soil organic matter as well as crop yield. Quantifying NUE based on cropping system evaluations is an improved approach over single-year assessments; however, long time periods are required, and errors associated with the measurements make accurate quantification problematic.

A long-term, field-scale cropping systems study under continuous no-tillage was established on a 92 acre field at the Washington State University Cook Agronomy Farm (CAF) near Pullman, WA, in 1998. Previously, the field was managed under conventional tillage. Georeferenced sampling locations were determined at the onset of the study to allow for grain, biomass, and soil samples to be collected from the same locations over the course of the study (Figure 1). Spring wheat (SW) was planted in 1999, spring barley (SB) in 2000, and then different three-year crop rotations of spring wheat, winter wheat (WW), and alternative crops (spring or winter plantings of barley (B), canola (C), or pea (P)). The 92 acre field was divided into three smaller fields (fields A, B, and C), and each part of all crop rotations was represented every year.

We took soil samples before the conversion from conventional tillage to no-tillage in the fall of 1998 (Figure 1). No differences in overall soil nitrogen were found among the three small fields in 1998, and soil nitrogen averaged 4,700 pounds per acre for the 0- to 1-foot soil depth and 8,450 pounds per acre for the 1- to 5-foot depth (Table 1). Different soil series had dissimilar amounts of soil profile nitrogen, with Caldwell silt loams having the most soil nitrogen and Staley silt loams the least amount for the 0- to 1-foot and 1- to 5-foot depths (Table 1).

After ten years (2008), soil samples were collected from the same georeferenced locations. Overall, soil nitrogen concentration had increased from 13.1% (1998) to 16.4% (2008) for the 0- to 1-foot depth and from 4.2% (1998) to 4.5% (2008) for the 1- to

Soil series	Taxonomic classification	Sampling locations	Soil N 1998 (0–1 feet)	Soil N 2008 (0–1 feet)	Soil N 1998 (1–5 feet)	Soil N 2008 (1–5 feet)	Soil N 1998 (0–5 feet)	Soil N 2008 (0–5 feet)
	Field survey		pounds per acre	pounds per acre	pounds per acre	pounds per acre	pounds per acre	pounds per acre
Staley	Fine-silty, mixed, superactive, mesic Calcic Haploxerolls	15	4,265	4,443	6,754	7,628	11,019	12,071
Naff	Fine-silty, mixed, superactive, mesic Typic Argixerolls	23	4,327	4,711	7,610	8,369	11,938	13,080
Palouse	Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls	90	4,693	5,175	8,628	9,011	13,321	14,186
Thatuna	Fine-silty, mixed, superactive, mesic Oxyaquic Argixerolls	42	5,023	5,255	8,984	9,689	13,999	14,953
Latah	Fine, mixed, superactive, mesic Xeric Argialbolls	11	4,800	5,228	8,744	9,993	13,544	15,221
Caldwell	Fine-silty, mixed, superactive, mesic Cumulic Haploxerolls	2	5,335	5,817	10,126	10,376	15,462	16,193
All		183	4,741	5,105	8,474	9,178	13,215	14,283

Table 1. *Total soil nitrogen (N) (pounds per acre) based on soil series taxonomic classification at three sampling depths (0 to 1 foot, 1 to 5 feet, and 0 to 5 feet) for the 92 acre Washington State University Cook Agronomy farm.*

	Mass balance	NUE	Nitrogen balance
Crop sequence†	0–1 feet (pounds per acre)	0–1 feet (%)	index (%)
SW-WW-SB	-239	82	54
SW-WW-SC	-382	72	50
SW-WW-SP	-184	88	52
SW-WW-WB	-471	65	47
SW-WW-WC	-257	81	50
SW-WW-WP	-190	85	50

†SW = spring wheat; WW = winter wheat; SB = spring barley; SC = spring canola; SP = spring pea; WB = winter barley; WC = winter canola; WP = winter pea.

Table 2. *Total soil nitrogen (N) mass balance (pounds per acre) and nitrogen use efficiency (NUE) (%) by crop rotation based on the 0- to 1-foot sampling depth and the N balance index (%) for the 92 acre Washington State University Cook Agronomy farm.*

5-foot depth. Low soil nitrogen concentration in the 1- to 5-foot depth may be a source of error in overall soil profile nitrogen calculations, as soil nitrogen concentrations are combined with soil bulk densities to determine soil nitrogen (lbs/acre). Errors generated from low nitrogen concentrations may be an inherent limitation to the study.

Soil profile nitrogen at 0 to 5 feet increased by approximately 35 pounds per acre per year following the conversion from conventional tillage to continuous no-tillage. The increase in soil profile nitrogen can be attributed to increases in soil organic matter following the conversion to no-tillage. While soil nitrogen increased on average for the entire field, there was considerable variability within the field, where soil nitrogen either increased or decreased from 1998 through 2008 (Figures 1 and 2). Although the crop rotations had been in place for eight years, no statistical differences in soil nitrogen among the different rotations were detected.

Nitrogen mass balance (Equation 1) and NUE (Equation 2) were calculated for each cropping systems based on 0- to 1-foot and 0- to 5-foot soil depths as follows:

$$\text{N mass balance} = \text{Soil N in 2008} - (\text{Initial soil N (1998)} + \text{Total applied fertilizer N (1998 – 2008)} - \text{Total harvested grain N (1998 – 2008)}) \quad [1]$$

$$\text{Cropping system NUE (\%)} = \left(\frac{\text{Total harvested grain N} + (\text{Soil N 2008} - \text{Soil N 1998})}{\text{Total applied fertilizer N}}\right) \text{x } 100 \quad [2]$$

All rotations gained soil nitrogen throughout the top foot of the soil profile; however, all had a negative mass balance (Table 2), indicating losses of nitrogen from the system (not directly measured). Nitrogen concentrations in the subsoil were low, which could result in analytical and mass balance calculation errors. This is why the focus of this study is on the top foot of the soil profile. Not all nitrogen inputs (e.g., N_2 fixation, atmospheric deposition) and outputs (e.g., leaching, denitrification) were directly measured in this study.

Overall, the cropping system NUE calculated from this multiyear study ranged from 65% to 88% and was over two times greater than that typically reported for a single growing season (20% to 40%) (Table 2). In addition, we did not have any significant differences in NUE or nitrogen balance index (Equation 3) due to crop rotation (Table 2), and all rotations at the CAF appear to be efficient users of available soil nitrogen.

$$\text{N balance index (\%)} = \left(\frac{\text{Total harvested grain N}}{\text{Total applied fertilizer N}}\right) \text{x } 100 \quad [3]$$

As the research continues, our understanding of no-tillage cropping systems and nitrogen pathway effects on NUE will improve, leading to more informed cropping system recommendations for managing nitrogen more efficiently throughout the high precipitation zone within the REACCH region.

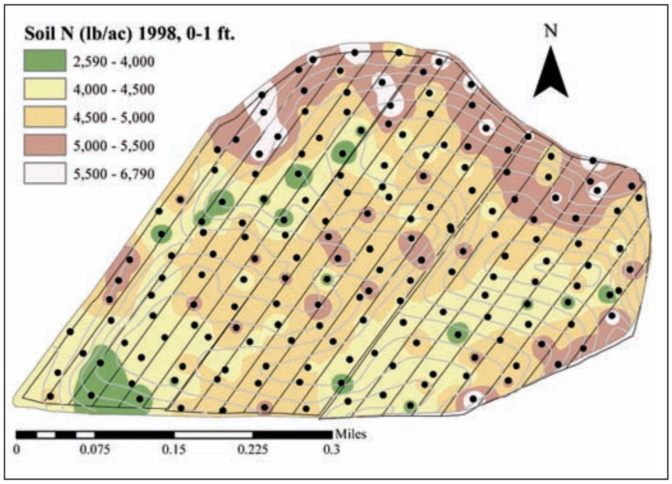

Figure 1. *Total soil nitrogen (pounds per acre) for the 0- to 1-foot sampling depth in 1998 at the Cook Agronomy Farm. Georeferenced sampling locations are marked as black points, and gray lines are contour intervals (9.8 feet). Field strips where different crop rotations were established are bounded by black lines.*

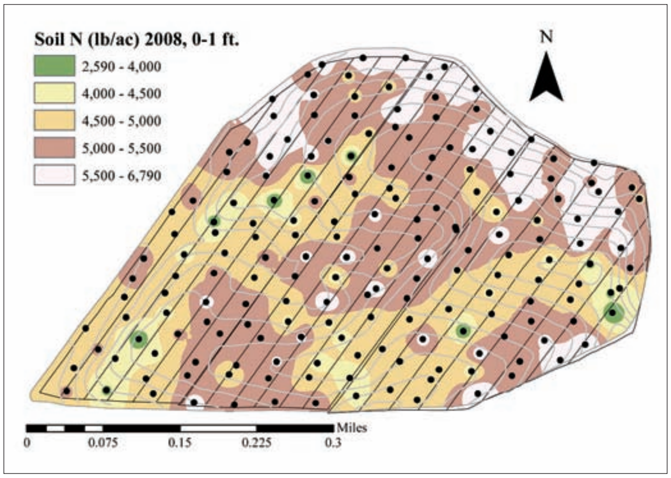

Figure 2. *Total soil nitrogen (pounds per acre) at the 0- to 1-foot sampling depth in 2008 on the Cook Agronomy Farm. Georeferenced sampling locations are marked as black points, and gray lines are contour intervals (9.8 feet). Field strips where different crop rotations were established are bounded by black lines.*

Seasonal dynamics of N_2O and CO_2 emissions

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The magnitude of nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions is affected by diurnal and seasonal fluctuations in temperature, moisture, availability of nitrate (NO_3-N) and ammonium (NH_4-N), and soil microbial activity. Rainfall during the fall and spring result in high N_2O and CO_2 emissions due to spikes in microbial activity upon soil rewetting. Thawing events during the winter result in an increase of greenhouse gas (GHG) emissions followed by a reduction in emissions in subzero temperatures. Application of fertilizer nitrogen prior to winter wheat planting in the fall increases the likelihood of GHG emissions due to increased availability of NO_3-N and NH_4-N. The current study was designed to assess the seasonal dynamics of N_2O and CO_2 emissions in dryland, no-till winter wheat systems.

IMPACT

Predicting the effects of agricultural management practices on global climate change requires an accurate assessment of diurnal and seasonal dynamics of soil greenhouse gas emissions. The study addresses the role of soil moisture, temperature, and freeze-thaw events in the production of nitrous oxide and carbon dioxide. The project is designed to provide a better estimate of annual greenhouse gas emission rates.

The no-till winter wheat site at Cook Agronomy Farm near Pullman, WA, was equipped with the Li-Cor 8100A combined with the LGR 23r N_2O analyzer and 16 long-term Li-Cor chambers placed in four replications at four elevation positions along the slope. Each chamber was paired with a Decagon 5™ soil temperature and moisture probe. Before installing the setup, we planted the wheat and fertilized the site with the agronomic rate of anhydrous ammonia fertilizer. The experiment ran continuously from October 2013 to September 2014. During snowfall events, we interrupted the measurements to prevent damage to the chamber domes due to snow obstruction. At the end of each snowfall event, we removed the snow from the chamber closure to ensure resumption of measurements in a timely manner. In the spring and summer, we trimmed the wheat inside the chambers to prevent CO_2 uptake, which could affect the measurements.

Emissions of N_2O increased following the rainfall in November, likely due to an increase in microbial activity leading to nitrification (Figures 1a, 1b, and 1c). In early December 2013, we observed a decrease in N_2O emissions as the temperatures dropped to near zero at night (Figure 1d). An increase in soil moisture during the day fron the end of December 2013 to early January 2014 resulted in spikes of N_2O emissions to 20 to 30 g N_2O-N meters^2 per hour (Figure 1b). During several consecutive snowfall events and thawing in January through March 2014, N_2O rates went up to 50 to 70 grams N_2O-N meters^2 per hour, with a

Snow removal from automatic static chambers at the long-term nitrous oxide and carbon dioxide monitoring site. Photo by Sarah Waldo.

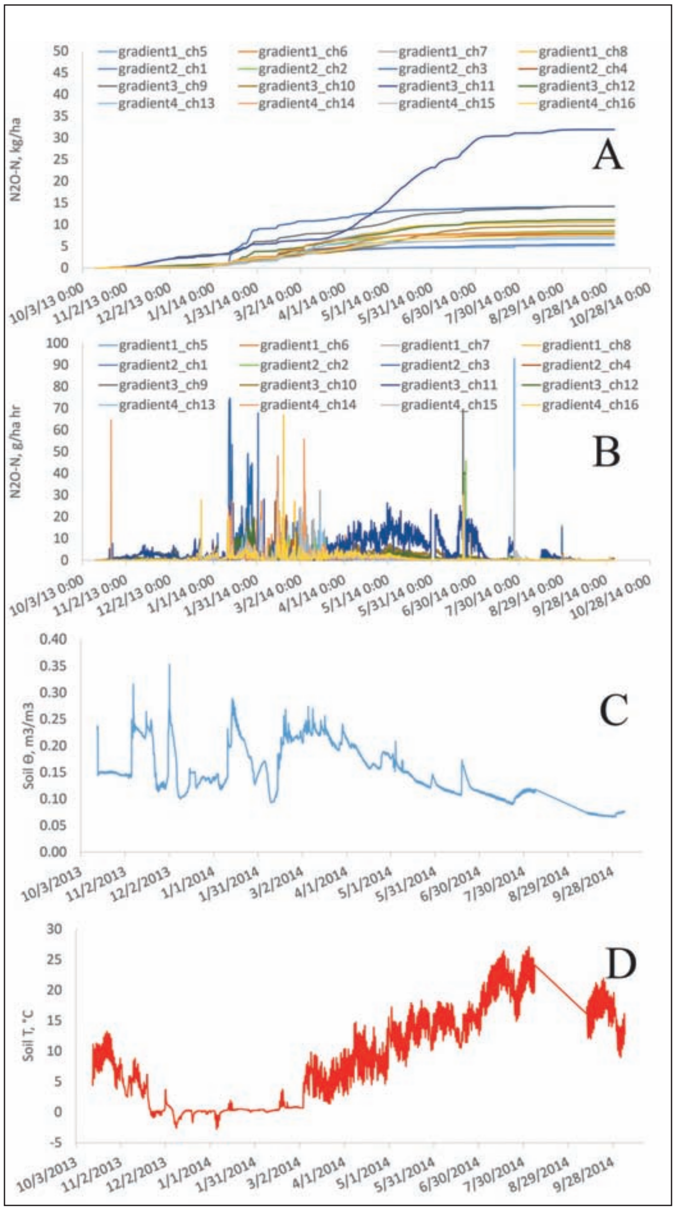

Figure 1. *Emissions of nitrous oxide (N_2O) and cumulative N_2O rates from October 2013 to September 2014 in a no-till winter wheat site in the PNW. Conversion factor: grams per hectare x 0.0009 = pounds per acre.*

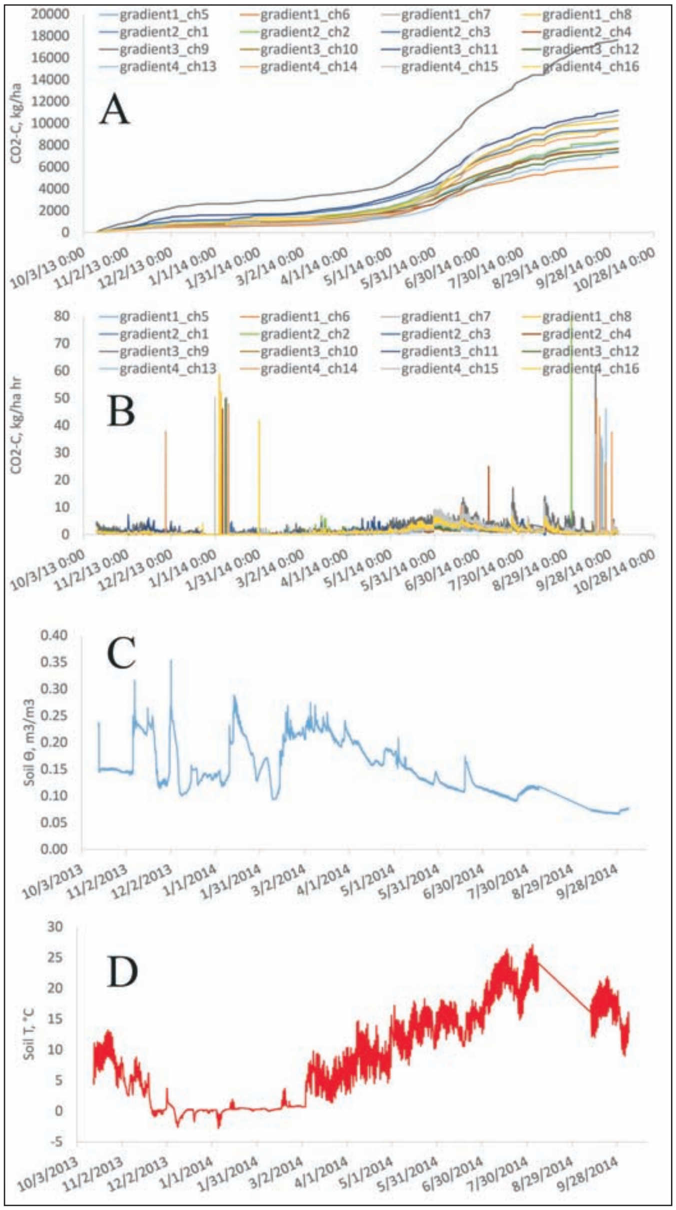

Figure 2. *Emissions of carbon dioxide (CO_2) and cumulative CO_2 rates during October 2013 through September 2014 in a no-till winter wheat site in the PNW.*

decrease in N_2O emissions when the moisture levels decreased. Emissions of N_2O started to decrease from March to May 2014 when increasing temperatures drew down the soil moisture levels. Several N_2O spikes in May through August 2014 occurred during rainfall events.

CO_2 emissions remained steady and then increased during rainfall events, then largely decreased with the reduction in daily temperatures in November and December 2013 (Figures 2a and b). Emissions of CO_2 spiked to 60 kilograms CO_2-C per hectare per hour following the pattern of N_2O emissions during the thawing periods in December 2013 (Figures 2c and d). CO_2 levels decreased rapidly after the freeze-thaw events and were relatively low in February through March 2014, during the times when N_2O emissions were high. As CO_2 followed N_2O only during the freeze-thaw period, it suggested that frozen water film possibly trapped N_2O and CO_2 in the soil pore space, and then released large quantities of GHG when it melted. Another possible factor affecting N_2O and CO_2 spikes was an increase in microbial activity during freeze-thaw events, which supplied water from thawing ice. CO_2 emissions went up during the spring of 2014, but, unlike N_2O emissions, continued to increase into May and June 2014. Increases in CO_2 in July and August occurred following the rainfall events. Several spikes of CO_2 were observed in the second part of September 2014, possibly due to an increase in organic matter following wheat harvest.

The total N_2O-N loss was 5% to 8% of the agronomic nitrogen application rates. Maximum N_2O emissions occurred between December 2013 and April 2014. Late spring and summer emission hot spots were associated with rainfall events. This shows the significance of freeze-thaw events and elevated moisture levels in the winter and early spring as major factors contributing to emissions of N_2O. The study emphasized the importance of N_2O and CO_2 measurements during the winter period in accounting for total GHG emissions.

Nitrification and denitrification pools of N_2O: Acetylene inhibition study

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Soil moisture is one of the factors affecting emissions of nitrous oxide (N_2O), a highly potent greenhouse gas that is a major contributor to climate change from agricultural land. Water present in soil fills the pore space, decreasing the oxygen concentration and creating anoxic conditions that favor reductive processes. Dry soil allows for higher oxygen levels, resulting in an increase in oxidative processes. N_2O is a by-product of ammonia oxidation (nitrification) and reduction in nitrate (denitrification), which occur under oxidative and reductive conditions, respectively. To be able to mitigate the effects of agricultural practices on global climate change, it is necessary to assess nitrification and denitrification pools of N_2O. We used a well-known substrate, acetylene, to prevent nitrification and therefore eliminate the respective pool of N_2O by deactivating the ammonia monooxyhygenase enzyme, which catalyzes the ammonia oxidation process. The inhibition reaction happens at 0.1 to 10Pa (0.01%) concentrations of acetylene. At 100Pa (0.1%) concentrations, acetylene also affects denitrification by inhibiting the reduction of N_2O to nitrogen gas.

IMPACT

To mitigate the effects of agricultural practices on global climate change, it is necessary to assess nitrification and denitrification pools of nitrous oxide (N_2O). The study helps us understand the scale of these processes in the irrigated system. This experiment is designed to develop best predictions for the sources of N_2O emissions at variable moisture levels.

We evaluated the effects of acetylene injection in situ, with nitrogen and repeat water additions, on carbon dioxide (CO_2) and N_2O emissions in the long-term no-tillage winter wheat site at Palouse Conservation Field Station in Pullman, WA. We implemented two Li-Cors 8100A coupled with two LGR 23r N_2O analyzers in continuous flow through a chamber system for monitoring CO_2 and N_2O emissions in the short-term microplot study between September 11 and 21, 2013. On September 11, 2013, we established the treatments with and without ammonium nitrate (NH_4NO_3) at at 150 kilograms N per hectare (134 pounds N per acre) fertilization and acetylene injection at 0.01% immediately following additions of water to saturation and fertilization (0 hours), as well as 12 hours and 24 hours later. On September 15, 2013, we modified the nonfertilized treatments to include ammonium nitrate (NH_4NO_3) at 134 134 pounds N per acre fertilizer and modified the acetylene levels to include the 0.1%, 0.01%, and no acetylene levels. We repeatedly added water to the plots to saturation in order to obtain the N_2O emissions at a range of moisture levels (Figure 1).

A soil core incubation was established concurrently with the in situ acetylene injection study, because this technique is widely used by researchers to obtain nitrification to denitrification as well as potential denitrification ratios to predict actual and potential denitrification for field chamber data. Soil cores from a depth of 8 inches (20 centimeters) were placed in 12 inch (30 centimeter) clear plastic tubes, which were inserted in soil in the field adjacent to the chamber study. We established the soil core treatments at 150 kilogram N per acre at 0.01% of acetylene and no acetylene at 90%, 60%, and 30% water-filled pore space (WFPS), as well as 0.1% of acetylene at 90% WFPS. The cores

Automated static chambers monitor greenhouse gas emissions on microplots for a study designed to help predict sources of nitrous oxide emissions at different moisture levels. Photo by Kirill Kostyanovsky.

were maintained sealed for 22 hours at a time; an air sample from the headspace of each core was then collected and analyzed in the laboratory on a gas chromatograph for N_2O concentration. The experiments were conducted following harvest during the times most likely to be affected by increased temperatures.

The initial nitrogen fertilization and additions of water resulted in higher N_2O emissions from the fertilized treatments than from the treatments with no fertilizer added. Effects of acetylene injection timing on N_2O emissions were detected only from the injection at 0 hours, likely due to acetylene efficiently penetrating the soil pore space only prior to saturation with water during the first several days of the study (Figures 1a and 1b). Further repeat additions of water and acetylene injections resulted in decreased N_2O emissions from all 0.01% acetylene treatments compared to no acetylene treatment, and in increased N_2O levels in 0.1% acetylene treatments (Figures 1c and 1d). This showed that multiple water additions and acetylene injections could be efficient in blocking nitrification and reduction of N_2O to N_2.

The levels of N_2O were highest in the 90% WFPS with no acetylene treatment in the soil core incubation study (Figures 2a and 2c). This was indicative of both nitrification- and denitrification-borne N_2O production upon initial wetting at near saturation levels. The fraction of N_2O originating from denitrification was 0.93 at 60% WFPS, 0.48 at 90% WFPS, and 0.1 at 30% WFPS. This was likely due to the slow rate of nitrification in the 90% WFPS treatment, resulting in prolonged nitrification-borne N_2O emissions compared to the 60% WFPS treatment, which favors faster nitrification due and yet had sufficient moisture levels for denitrification to occur. Denitrification potential at 90% WFPS was two times higher than actual N_2O emissions and eight times higher than the level of N_2O from denitrification (Figures 2b and 2d). Predicted levels of denitrification based on the core incubation data matched well with the measured denitrification levels after several water additions and acetylene injections (Figure 3). Our data showed that 85% to-88% of all N_2O emissions in the field study originated from denitrification.

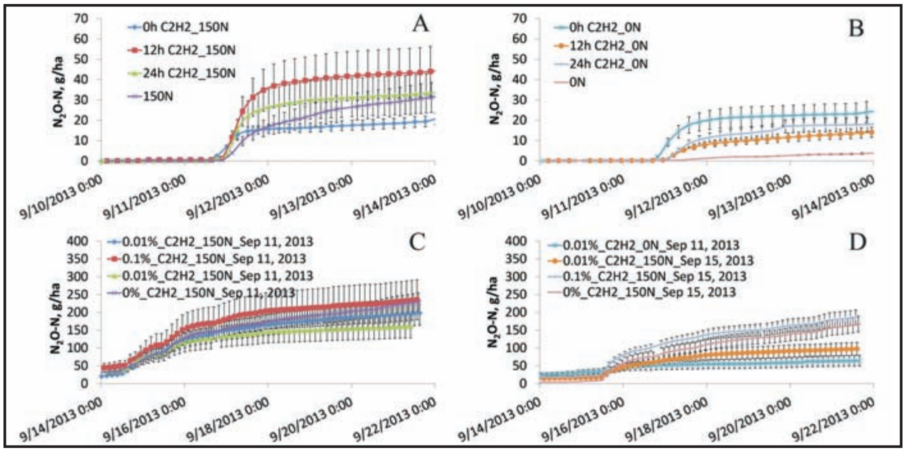

Figure 1. *Emissions of nitrous oxide with and without additions of ammonium nitrate 134 pounds NH_4NO_3-N per acre and acetylene injection in situ in the chamber microplot study.*

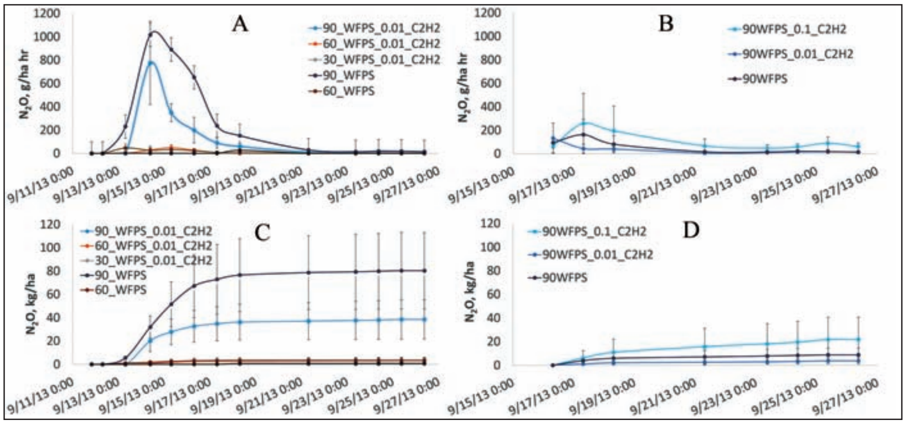

Figure 2. *Levels of nitrous oxide with and without additions of 134 pounds NH_4NO_3-N per acre and acetylene additions in the soil core incubation study.*

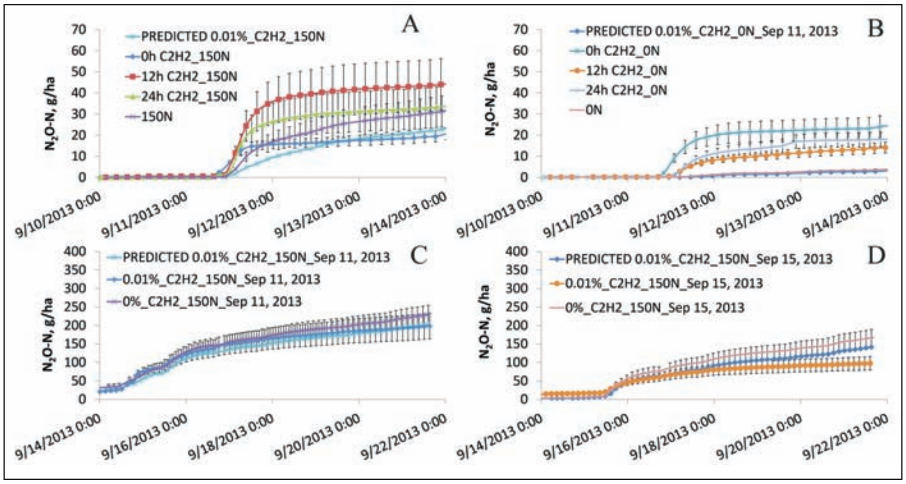

Figure 3. *Predicted levels of denitrification-borne nitrous oxide (N_2O) compared to in situ levels of N_2O with and without additions of 134 pounds NH_4NO_3-N per acre and acetylene injection in situ in the chamber microplot study.*

Overall, the soil core incubation experiment demonstrated much higher rates of N_2O emissions than the in situ chamber microplot study. Lower cumulative rates of N_2O in the microplot study were likely a result of short-lived spikes in soil moisture due to drainage, even with repeat water additions. Another likely factor was decreased retention of ammonia and nitrate in the soil due to rapid nitrification and leaching of nitrogen with added water. The study showed that in situ chamber measurements are required to obtain realistic N_2O emission values.

Managing excess water in the high-precipitation zone

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Growers in the wetter eastern annual-cropping region of the Pacific Northwest do not have a problem with too little winter precipitation, but instead must find ways to manage excess soil moisture conditions during the early spring months. Not only does the precipitation increase in the eastern edges of the REACCH region, but the soils in the wetter, eastern borders of the region also generally have higher clay content and develop dense, restrictive soil horizons, further exacerbating the problem of excess moisture. The dense horizons are called argillic (Argixerolls) and fragipan (Fragixeralfs), with the latter horizons often being nearly impermeable to water (Figure 1). In fields with steep converging topography, toe-slope positions often remain completely saturated for weeks on end during early spring months, due to poor drainage through these horizons. The depth of these argillic and fragipan horizons generally varies throughout a field, with very shallow (~0.7-feet) horizons in eroded ridge locations and much deeper ones in toe-slope deposition regions (~3 to 5 feet).

IMPACT

Future climate projections suggest that increased winter precipitation will exacerbate runoff and erosion problems in the high-precipitation zones of the Palouse, most significantly for those growers in the annual cropping region where soils have restrictive horizons. With an increase in spring moisture predicted for the late spring months, growers may need to consider incorporating more fall-seeded crops into their rotations and relying on more spring fertilizer applications, as overwinter nitrogen losses will also likely increase.

Since these restrictive horizons are often too deep and thick to be broken down by most tillage implements, little can be done to increase water flow through these layers. In many regions, these toe slopes are artificially drained using tile lines or 4-inch perforated artificial drains to allow growers to access their fields earlier in the spring.

In the REACCH and Site-Specific Climate-Friendly Farming projects, we are using physically based, hydrologic sediment transport and cropping systems models to investigate the impact of various management strategies on sediment and nutrient transport in this high-precipitation zone. We are using the Water Erosion Prediction Project (WEPP) model to evaluate the impact of management on surface runoff, drainage, soil erosion, and carbon loss. Similarly, we have been using a newly developed 3-D version of the CropSyst model called MicroBasin to investigate the importance of the depth of a restrictive layer for the hydrology, crop production, and nutrient transport within a field. By using downscaled future climate data, we can use these models to evaluate the effects of management and soil properties on both current and future climates. Future climate projections indicate that the region will experience a 3° to 7°F increase in temperature and wetter (by ~1.5 to 3 inches) winters and slightly drier summers.

Both the WEPP model and the MicroBasin model suggest that the presence of restrictive soil horizons greatly affects the distribution of water throughout a field. WEPP model simulations indicate that surface runoff from soil having a restrictive layer at 2.3 feet (1.4 inches per year) can be nearly 2.5 times greater than

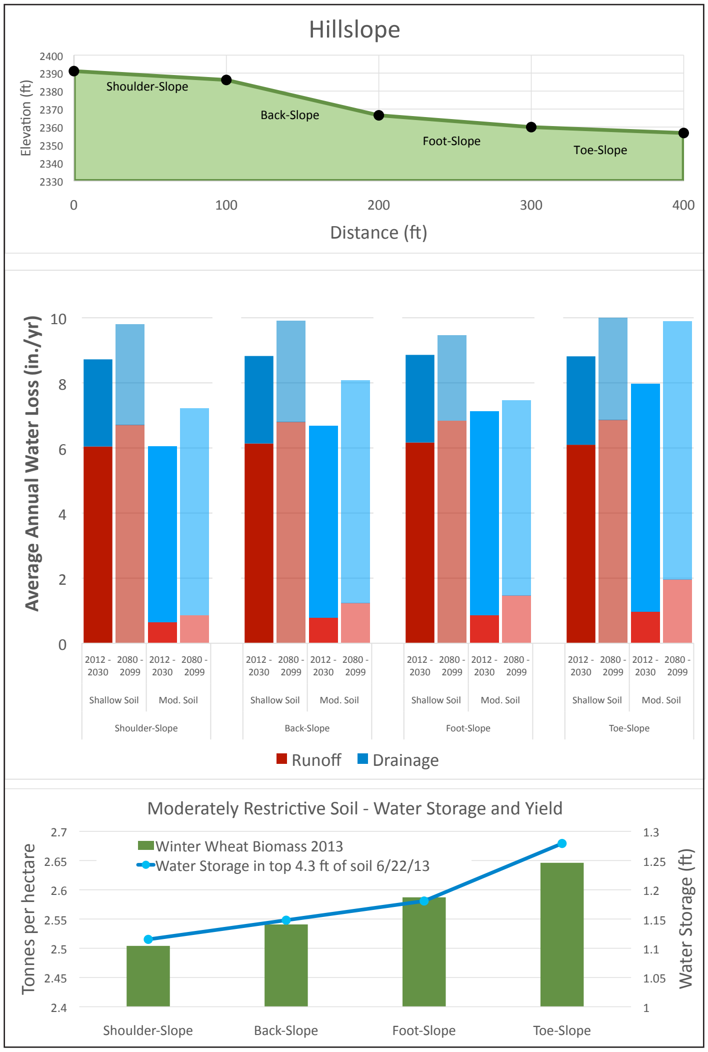


Figure 2. *Simulated runoff, drainage, and crop biomass production from soils that have a restrictive soil horizon at depths of 0.7 meter and 1.3 meter (2.30 and 4.27 feet) for early-century and late-century climates in the high-precipitation zone of the REACCH region.*

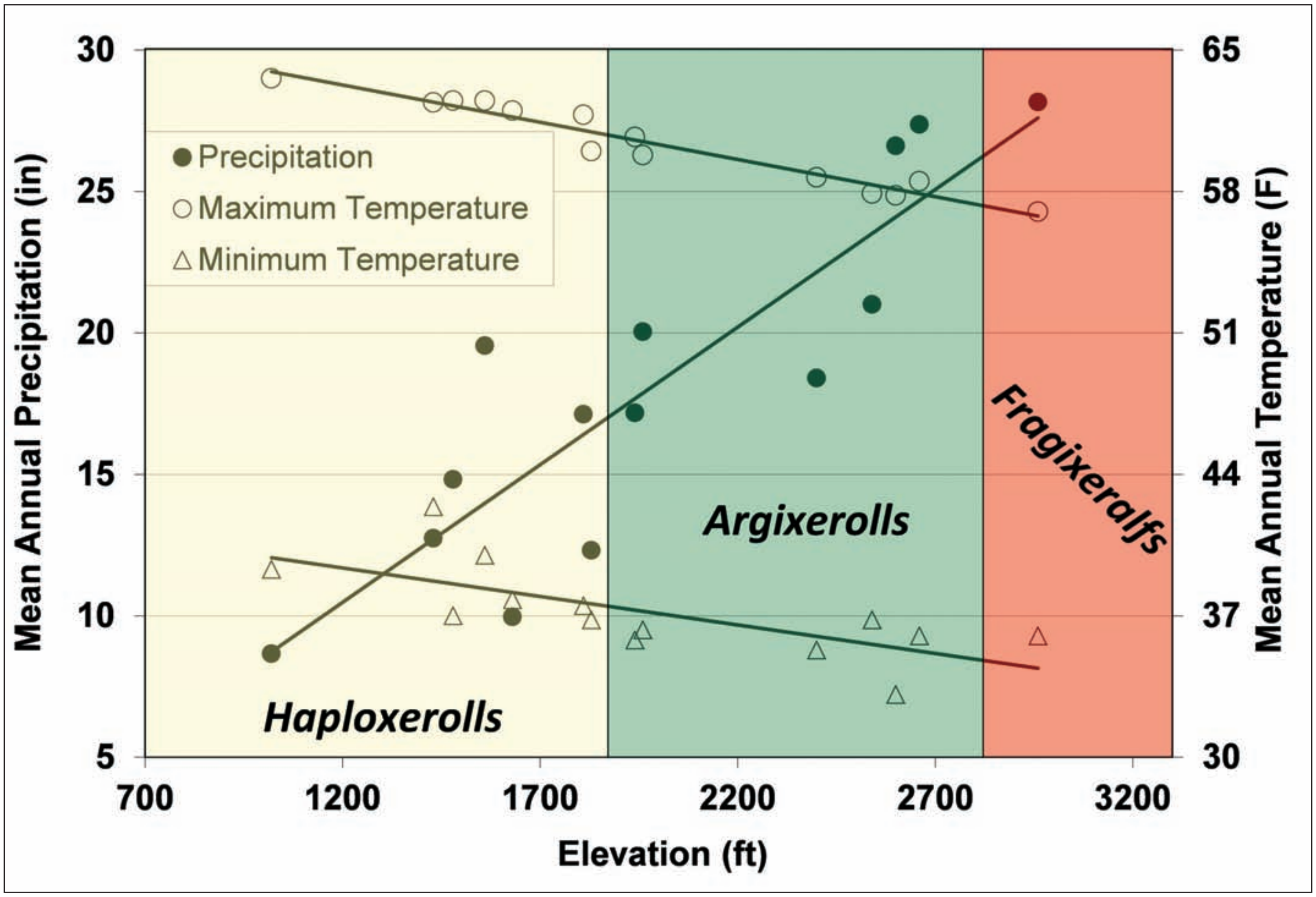


Figure 1. *Relationships among soils, mean annual precipitation, maximum temperature, minimum temperature, and elevation for distributed locations in Whitman County, WA, and Latah County, ID.*

surface runoff from a deep soil (3.3 inches per year), despite both soils being managed using no-till practices. Interestingly, the model shows that there is little difference in annual surface runoff from conventional tillage and no-tillage fields when the soils have a shallow restrictive layer. Despite high runoff, however, the adoption of no-till practices is very effective, nearly eliminating soil erosion in these shallow soils. This suggests that adoption of no-till practices can effectively reduce soil erosion and pollutants bound to soil particles by protecting the soil. However, no-till practices may be minimally effective at reducing runoff or any soluble pollutants carried along with runoff.

Both of these models also provide insight into the distribution of runoff and soil moisture throughout a landscape. Figure 2 shows the effect that the depth of a restrictive layer through a hill slope has on surface runoff, drainage, and crop biomass production, using the MicroBasin model. As seen in the figure, surface runoff from a shallow soil having a restrictive layer is much greater than that from a soil where the restrictive layer is located 4.3 feet (1.3 meters) below the soil surface. The model also demonstrates that the soil moisture is much more uniform throughout the hill slope for the shallow soil than for the 4.3-foot soil. The variability in soil moisture with the deeper soil is caused by more subsurface lateral redistribution of water from the shoulder and back slopes to the flatter toe-slope position. The increased soil moisture in the toe slope results in greater overall crop production, in contrast to the low crop production in the water-limited shoulder-slope area.

Interestingly, both the WEPP and MicroBasin models indicate that surface runoff, spring soil moisture levels, and soil erosion will increase in the latter half of the 21st century. With increased temperatures, summers will be drier, but the increase in winter precipitation will result in an overall annual increase in excess water. Over the next year we will be using the MicroBasin model to investigate the implications of this spatial variability in crop production on nitrogen fertilizer strategies and nitrate losses. With an increase in spring moisture predicted for late spring months, growers may need to consider incorporating more fall-seeded crops into their rotations and relying on more spring fertilizer applications, as overwinter nitrogen losses will also likely increase.

The impact of climate change on soil erosion

Paige Farrell (farr8438@vandals.uidaho.edu) UI, John Abatzoglou UI, and Erin Brooks UI

Projected changes in climate for the inland Pacific Northwest (PNW) as a result of increased greenhouse gas concentrations are warmer temperatures, increased winter precipitation, a larger proportion of precipitation falling as rain rather than snow, and an increase in the intensity of extreme precipitation events. These changes will alter the land-atmosphere relationship that the agricultural industry relies on to remain stable, predictable, and profitable. While some of the projected changes in climate may result in beneficial impacts for certain sectors, other changes may be detrimental. One of the goals of REACCH is to allow farmers to continue to be successful in a changing climate.

IMPACT

The sensitivity of soil erosion to climate change will affect the types of management farmers should consider using in the future. Understanding how a changing climate will affect soil loss can provide a framework of options for farmers and residents of the inland PNW that could help them more easily adapt to a changing climate.

While individual farmers may be unable to change the pace of global climate change through mitigation, they may be able to adapt to climate change and devise management practices that are more resilient to climate impacts. Soil erosion is among the climate-related impacts that concern dryland farmers in the REACCH study area, since conservation of topsoil is critical to sustained productivity in such systems. Moreover, knowledge of potential risks of soil erosion in a changing climate may help inform farmers' agricultural management decisions.

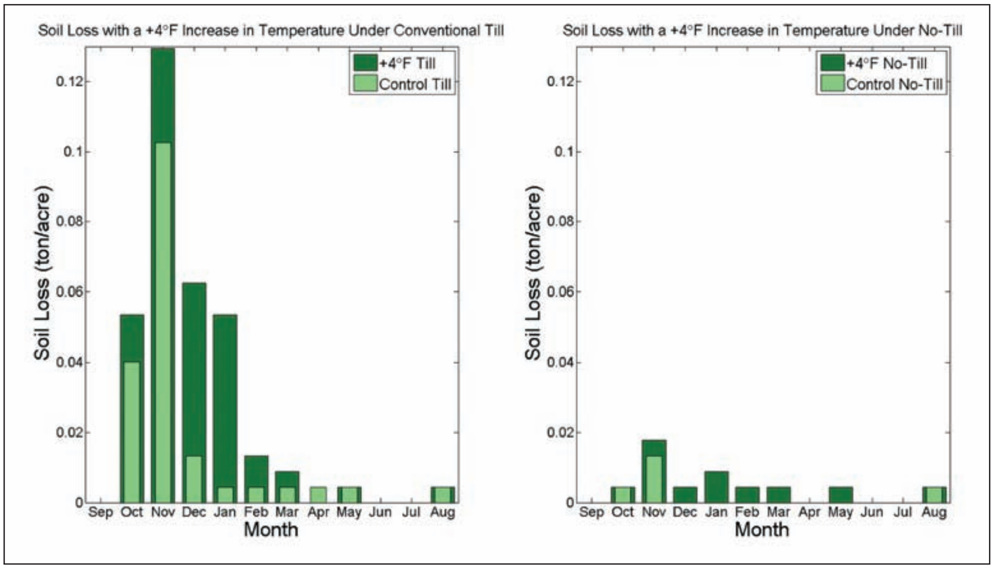


Figure 1. *Monthly average changes in soil loss on a moderately flat slope over a 30-year simulation.*

To gain a better understanding of the complex relationship between soil erosion rates and climate change, we examined the sensitivity of soil erosion to warming. While there is a broad range of projected changes in climate, including precipitation, we constrained our focus to a representative warming scenario for the mid-21st century of approximately 4°F. Because erosion rates vary depending on landscape and crop management factors, we considered varying hill slopes ranging from flat to steep and two types of cropping practices: conventional tillage and no-tillage. All of these factors were analyzed using the Water Erosion Prediction Project (WEPP) model for a site representative of the wetter eastern Palouse near Moscow, ID. The WEPP model allows for all of the different climatic variables and other environmental variables to predict soil loss, changes in biomass, winter erosion scenarios, and evapotranspiration.

Within the REACCH region, both increases and decreases in precipitation have a direct and relatively predictable impact on soil loss. However, the effects of warming temperatures on soil loss are more complex. Figure 1 shows changes in soil loss as a result of temperature change on a moderately flat slope compared to a control run that used historical surface meteorology from 1979 to 2009. Annual average changes in erosion under conventional tillage could increase from 0.17 tons per acre to 0.5 tons per acre, resulting in a 192% increase in soil loss.

Historically, soil loss rates are predictably highest in fall and winter months due to the onset of the rainy season following harvest, when crop cover is lowest and unable to buffer soil losses due to runoff events. Overall, fall and winter appear to be the seasons when erosion is most dominant. The warming experiment resulted in an increase in soil loss of about 30% during the late fall under conventional tillage practices, due to decreases in the snow water equivalent in addition to an increase in rain and melt (Figure 2). Even larger increases in erosion rates were found in December and January in the warming experiments, due to a dramatic decrease in the snowpack on the ground and increases in both rain and snowmelt in these months. Snow water equivalent represents the depth of water that would exist if you were to melt the snowpack on the ground. A decrease in snow water equivalent indicates less snowpack and therefore less pro-

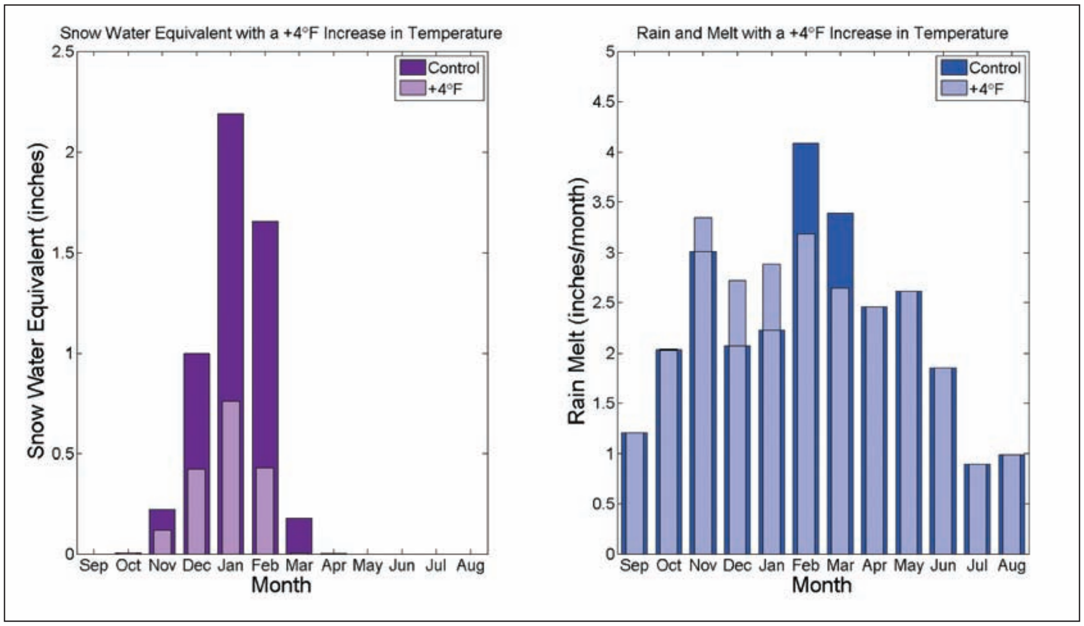


Figure 2. *Monthly change in frozen soil depth under both conventional tillage and no-tillage practices with an increase in temperature.*

tection of the soil. Likewise, with warming, more winter precipitation will fall as rain rather than snow and will facilitate more midwinter erosion events.

Although warming results in an increase in rain and a decrease in snow water equivalent into late winter, soil losses are tempered. We hypothesize that this is due to the early onset of biomass growth caused by warming, which buffers the soil from erosion-induced loss. Live crop biomass historically develops in the late winter and spring months with warming temperatures (Figure 3). In the warming experiments, live biomass increases by 140% to 260% in February through April. This increase in crop biomass minimizes warming-driven impacts on soil loss by creating insulation for the soil and decreasing erodibility.

Changes in soil loss occur on a much greater scale under conventional tillage practices than under no-tillage practices. The disparity between tillage decisions is a result of the fact that no-tillage practices result in limited perturbations to the soil, allowing it to stabilize and reducing its susceptibility to erosion, even under a warming scenario. In addition to temperature, precipitation and extreme precipitation can affect areas such as Moscow, ID through large runoff events and increased amounts of rain falling on snow. Understanding the various ways in which climate can affect soils and the landscape of the inland PNW can supplement local growers' knowledge and experience, providing a more comprehensive understanding of what changes the future may hold. Some areas within the region may be affected more by precipitation than by temperature. This type of analysis is relevant to many areas of the REACCH region, and we plan to provide similar analyses in other locations. Through this research we hope to help build a framework that will facilitate the prevention of devastating soil losses that may occur as a result of climate change in the region.

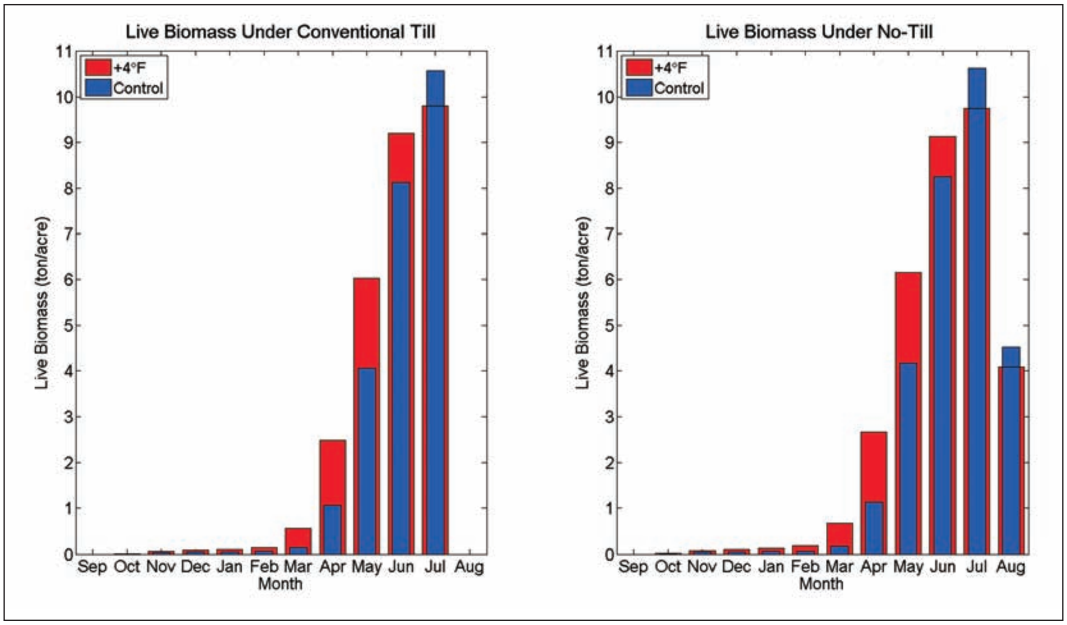


Figure 3. *Monthly amount of live biomass with no climate change (left) and with an increase in temperature (right).*

Determining the controls on nitrogen uptake from space

Troy Magney (tmagney@uidaho.edu) UI, Matt Yourek UI, Nicole Ward UI, Sam Finch UI, Jan Eitel UI, Lee Vierling UI, Erin Brooks UI, Dave Huggins USDA-ARS, and Dave Brown WSU

The word "determine" in the title should come with a caveat. While more advanced technologies are being marketed to growers as must-have tools for precision farm management (e.g., drones), caution is advisable before hasty adoption. Precision agriculture and remote sensing technologies are not fully capable of "determining," say, exactly how much fertilizer should be applied where; rather, they can provide us with a map of how crop patterns vary across a field in both time and space. Further, highly resolved satellite images, such as the ones described in this research, do not provide us with a process-based understanding of what is driving these patterns. To begin to understand the controls on crop nitrogen uptake, for example, we can use geostatistical approaches, ranging from simple to complex, to compare crop patterns with ancillary information on what is actually happening in the soil. Using a combination of data and models that provide maps of soil, water, and weather conditions together with satellite maps of crop variability will enable us to analyze why some parts of a field might be consuming more nitrogen than others.

IMPACT

Satellite imagery provides a means to estimate the patterns of crop nitrogen uptake from space. With this information, growers can begin to use these patterns to determine zones as a way to maximize the efficiency of fertilizer application. When coupled with soil and water information, these zones will help growers determine the specific factors that are driving these patterns.

The widespread adoption of precision agriculture has been guided by the idea of devising a decision support system to optimize returns on inputs while reducing the economic and environmental consequences of overapplication. Many growers and crop consultants currently use historical yield maps to determine nitrogen management zones. In the Palouse, where patterns of soil water content in this notoriously heterogeneous landscape have a large influence on crop productivity, a greater understanding of the spatiotemporal variability of factors that affect crop nitrogen use efficiency (NUE) and water use is needed. As a first cut to investigate this, we used images taken every 10 (or so) days by the RapidEye-BlackBridge™ satellite system with a 17-foot spatial resolution (pixel size) and compared them to a widely used model, called Soil Moisture Routing (SMR), which provides a map of daily soil volumetric water content (SVWC) across the field. This article will focus on a spring wheat crop at a farm in Colfax, WA, during the 2013 growing season.

Before using a model or satellite image to infer a process, we first need to validate how well this tool actually measures what we are interested in. Figures 1 and 2 demonstrate some of the validation steps we used to understand not only how accurately the model performs, but also how much uncertainty is inherent in the model. Figure 1 shows the temporal trend of soil water over two seasons for one particular point where SVWC has been measured. It can be observed that both the magnitude and the timing of the observed (actual) and predicted (model) SVWC values at this site are remarkably similar.

To validate the satellite image (Figure 2), we first needed to decide what variable we were interested in mapping. Because reflected solar energy from vegetation is primarily a product of leaf area (biomass) and chlorophyll content, satellite measurements of plants are primarily related to these two biophysical properties. However, in an effort to understand where management zones should be located, a grower might be interested in how much nitrogen is actually removed from the ground and into the standing crop. Fortunately, the amount of nitrogen in wheat (used here) is highly correlated to total aboveground chlorophyll (chlorophyll concentration multiplied by leaf area). The simple regression output in Figure 2 shows that by using a particular combination

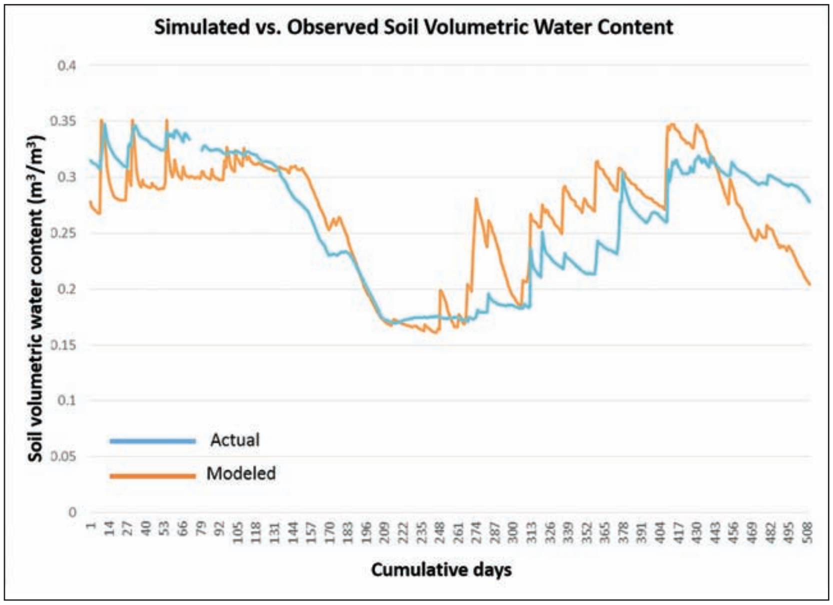


Figure 1. *Comparison of modeled (using the Soil Moisture Routing model) temporal variability of soil water at one site on the Colfax, WA, farm to actual soil water measured from a Decagon soil moisture probe.*

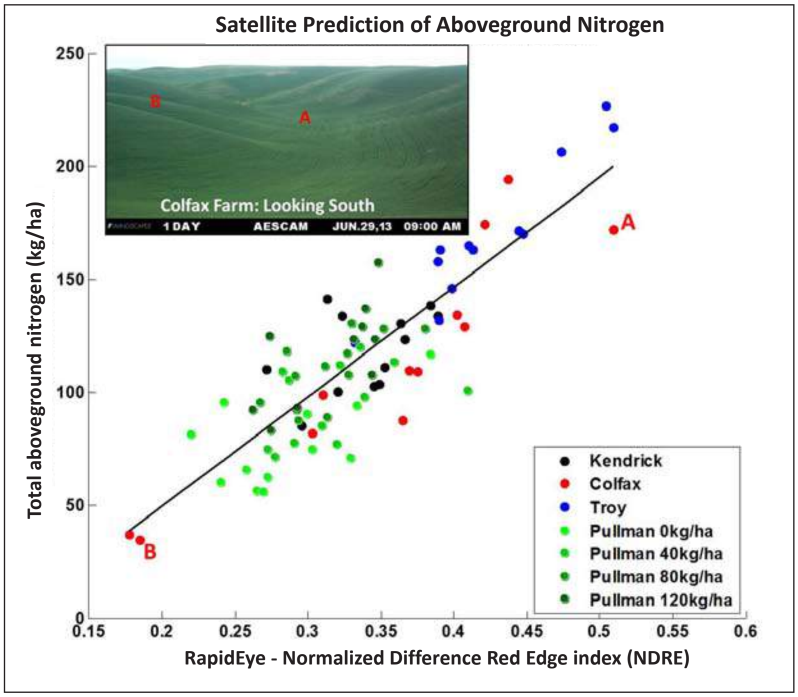


Figure 2. *Validation of the satellite-derived Normalized Difference Red-Edge Index (NDRE) in estimating total aboveground nitrogen. RapidEye satellite images were taken at peak biomass and compared with harvested total biomass multiplied by nitrogen concentration at four farms across the Palouse. Dots in different shades of green represent fertilizer treatments at study plots. (kilograms per hectare x 0.89 = pounds per acre)*

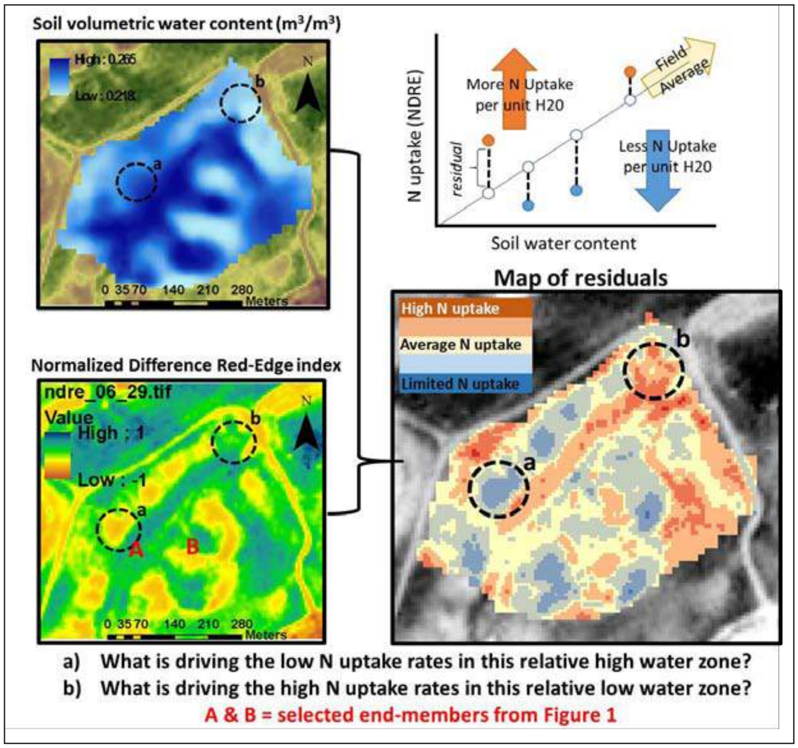


Figure 3. *Schematic illustrating the approach of combining data from the soil moisture routing model (top left) and the satellite image (bottom left, where a high value is used as an indicator of greater nitrogen uptake by the plant) to tease apart areas of the field that deviate from the average rate of nitrogen uptake per soil water content (bottom right). The top-right panel was designed to illustrate how the residuals map was created.*

of satellite "bands," the near-infrared and red-edge bands, we can get a pretty good estimate of nitrogen in the plant ($R^2 = 0.72$), especially compared to the digital photo in Figure 2, which was taken on the same day, with the same "bands" we see with our own eyes (see "Using time-lapse imagery for applied agricultural monitoring" later in this report page 102). The near-infrared and red-edge bands outperformed any other combination of bands in this validation step, and are combined mathematically to create the Normalized Difference Red-Edge Index (or NDRE).

With this confidence, and an understanding of the model and satellite uncertainties, we can compare spatially where patterns of crop nitrogen uptake are consistent or deviate from soil water content (Figure 3). An ordinary least squares regression between the pixel values on these two maps can provide us with a field-scale average of how much nitrogen uptake occurs per SVWC (depicted in the top right of Figure 3). Using the distance (residual) from the field average, we can begin to elucidate areas that are very resource efficient (area *b* in the bottom-right map of Figure 3) and areas where nitrogen uptake is low compared to SVWC (area *a*). By locating the anomalies in these maps, we can use ancillary information such as weather, inputs, and soil conditions (often derived from other models such as CropSyst) to gain a better idea of what is driving plant nitrogen uptake across space and time. Our interdisciplinary team is currently working to investigate these processes further using other data sources. Eventually, maps similar to these will enable growers to develop decision support systems that can help them achieve the holy grail of maximizing outputs (yield) while minimizing inputs (fertilizer, pesticides, etc.).

Growing our roots: Climate science in secondary schools

Troy White (pwhite@uidaho.edu) UI, Kattlyn Wolf UI, and Jodi Johnson-Maynard UI

IMPACT

A curriculum that allows teachers to increase both climate science literacy and agricultural literacy will make students in the region more globally aware and productive members of society.

Finding ways to get climate science into secondary classrooms has presented a challenge to researchers, due to teachers' limited knowledge of the subject. Research across the region has suggested the need for curriculum and focused teacher in-service training directed at climate science literacy. To meet this need, we have developed an interdisciplinary curriculum that focuses on the use of agriculture as a context for teaching students about both agriculture and climate science. To help teachers better understand the new curriculum and the climate science embedded in it, we have offered professional development in-service courses each summer starting in 2012. A handful of REACCH teachers attended the first in-service training, which was grouped with ICE-NET, a University of Idaho climate literacy project in its final year.

In 2013, 18 teachers attended the first solo in-service training, and 8 high school teachers applied their experience to their own classrooms by piloting the first three REACCH curriculum units. Students and teachers alike took attitudinal questionnaires based on the Global Warming's Six Americas survey, which Harvard has been conducting for more than eight years. Students at each of the eight pilot high schools took this survey both before and after instruction. The surveys were supplemented by exit interviews with teachers to determine how the teachers felt about the quality of the curriculum and the receptiveness of the students to an agriculturally based climate literacy curriculum.

Teacher comments reflected two key findings. First, the curriculum was received positively in every school, and second, the students both gained knowledge and enjoyed the units of instruction. Teachers reported that their students related well to the

Figure 1. *Agricultural and natural science teachers learned how to collect weeds and pests in wheat fields in Pendleton, OR, July 2014. Despite the high temperatures, they collected more than 30 species for identification and preservation. Photo by Leigh Bernacchi.*

locally relevant curriculum, and could often provide correct examples from their own observations of how agriculturalists were adapting to the changing climate and modifying their production practices.

One component of the curriculum appreciated by teachers was the scientific readings provided for each unit. Teachers are trying to create new curriculum that ties their content area to the Common Core state standards. These standards were adopted in the Pacific Northwest (PNW) over the past two years, with increasing levels of accountability over three years and full accountability beginning in the 2014-15 school year. The English and Language Arts standards require teachers of all disciplines to have their students read technical and scientific publications of varying levels of complexity throughout their courses. The REACCH units all included at least three technical documents tied to the content of the units for teachers to use with their classes. Teachers reported that these readings were grade appropriate, and several were technical enough to really challenge their students. One teacher reported that she had successfully partnered with the Language Arts teacher at her school to use the readings in both classes to enhance the relevance of the agriculture curriculum for her students.

Student evaluations of the content showed gains in agricultural knowledge; however, attitudinal statements relating to climate science showed mixed results. The climate science covered in the soils, water, and erosion lessons was indirect in its application. The overall curriculum has units specifically on the changing climate, ecological processes, and economic impacts of climate change on agricultural production across the region. These units were not piloted as a complete curriculum, and so it was expected that students receiving only 3 of the 10 units would not demonstrate a full understanding of climate science. Because of this limitation, teacher interviews have provided the data relating to the impact of the curriculum on student attitudes related to climate change. All of the teachers in the pilot group reported that their students were more receptive to climate science because of their interaction with the REACCH units. Student attitudes in one school were actually more positive toward the reality of climate change than those of their teacher.

Figure 2. *Teachers Lynique Oveson and Brian Wolf collected weed species for preservation. They marked each weed with their GPS units. Incorporating live specimens with technology brings together multiple scientific techniques and gives the students a lot to do. Photo by Nicole Ward.*

Teachers in the region have not taught units on climate science in the past. Providing teachers with both a curriculum and in-service opportunities to become familiar with the science have proven beneficial for both REACCH and the pilot teachers. REACCH is currently piloting the next three units of the curriculum with 21 teachers spread across ID, OR, and WA. The pilot will continue in the summer of 2015 with the final units of the curriculum. The modified complete curriculum will be released in the spring of 2016 to help teachers meet the needs of high school students across the region.

Figure 3. *To understand the end of the wheat production process, the teacher workshop attendees were able to visit the Pendleton Flour Mill. This mill produces many types of flour for well-known brands and local restaurants, using regional wheat. Photo by Leigh Bernacchi.*

Water, soils, and erosion in the high school science classroom

Ryan Boylan (rboylan@uidaho.edu) UI, Chelsea Walsh UI, Hilary Davis UI, and Troy White UI

Educational research suggests that students are leaving high school ill prepared for science, technology, engineering, and mathematics (STEM) careers. International math and science literacy rankings from 2006 and 2012 placed students in the United States 21st of the 30 developed nations included in the rankings. These rankings, along with a growing gap in career readiness, prompted scientists, educators, and policy makers to call for a greater emphasis on STEM content and concepts in all science-related classrooms. Motivated to produce a better-trained workforce and maintain the United States' standing as a competitive and innovative leader in the global economy, educational leaders from across the nation collaborated to produce the Next Generation Science Standards (NGSS). These standards require students to develop a deep understanding of core disciplinary ideas, provide evidence of their knowledge through scientific and engineering-related activities, and connect concepts across disciplines.

IMPACT

Increasing math and science literacy for high school students entering the workforce has become an important priority in the United States. Lessons integrating multiple disciplines, illustrating links between climate change and agriculture, utilizing current relevant research, and aligning with the Next Generation Science Standards provide teachers and students with the resources they need to address these integrated standards.

To address the need for integrated hands-on lessons that fit within the NGSS framework, an interdisciplinary team of REACCH graduate students from the University of Idaho developed a Water and Erosion of the Soil unit for high school science and agricultural technology classrooms. The team, comprising graduate students in the disciplines of soil science, water resources management, economics, and education, developed the unit to be cost-effective for teachers to implement, include relevant scientific literature, align with NGSS, and incorporate aspects of each of the team members' research. The specific topics of soil infiltration, runoff, and erosion were selected because of their regional significance, importance to agriculture, and role in strategies for adapting to climate change in the Pacific Northwest (PNW). The dryland cropping areas of the inland Pacific Northwest and many other regions have a long history of soil erosion negatively affecting the environment and local economies, making the topic relevant to growers and local students alike (Figure 1). In addition, future climate scenarios could lead to erosion rates equal to or greater than those measured prior to the 1970s.

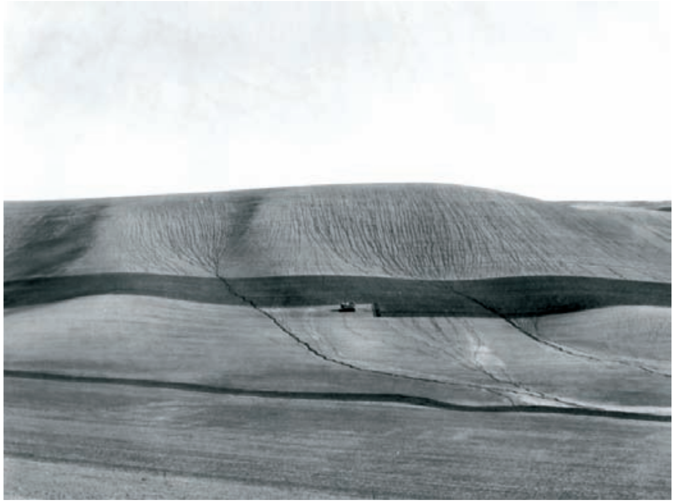


Figure 1. *Erosion on the Palouse, 1959. Photo by Verle Kaiser.*

Erosion on the Palouse hills south of Colfax in early February, 2011. Photo by Kathleen Painter.

Addressing interdisciplinary aspects of water and soil erosion and integrating the impacts of climate change required collaboration within the interdisciplinary team. A set of three PowerPoint presentations were developed to provide teachers with background information and visual aids. Each presentation focused on one of three major themes: hydrology, soil science, and modeling. The team integrated economic aspects with the hydrology and soil science lessons to provide real-life applications and relevance. An inquiry-based lab activity titled Soil Infiltration and Runoff (Figure 2) was developed to demonstrate principles covered in the PowerPoint presentations. In the lab, students are given the opportunity to physically model and measure runoff, soil erosion and infiltration under various rainfall intensities, slope steepness, and residue cover.

In addition, the team developed two lab extensions to address (1) the economics of soil water and erosion and (2) computer

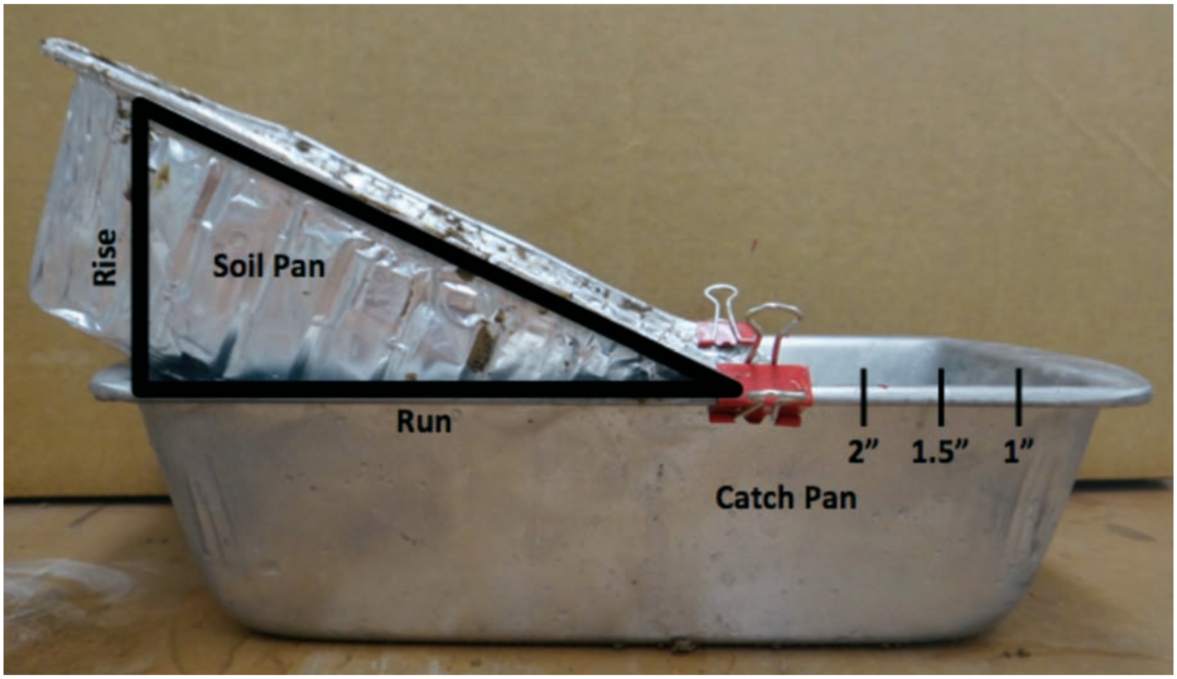


Figure 2. *Soil Infiltration and Runoff lab activity showing the setup of a baking pan full of soil students use in the classroom to measure runoff, erosion, and infiltration. Photo by Brad Stokes.*

modeling of runoff and erosion with the web-based Hydrologic Characterization Tool (HCT, wepp.ag.uidaho.edu/cgi-bin/HCT.pl). In the economics extension activity, students read selected pieces of scientific literature and complete a worksheet to calculate the effects of infiltration and erosion on crop yields. In the computer modeling activity, students simulate soil erosion and runoff, with the HCT mimicking what they physically modeled in the Soil Infiltration and Runoff lab. The students then simulate and explore different conservation measures in the model and examine the ability of these measures to mitigate runoff, sediment, and pollutant loads.

The Water and Erosion of the Soil unit was presented to 19 high school science and agricultural education teachers during the summer of 2013 at a REACCH-sponsored teacher workshop (Figure 3). Additionally, the unit was incorporated into a semester-long curriculum developed by the REACCH education team. The curriculum focuses on climate change issues in agriculture and integrates REACCH-related research. The participants in the 2013 teacher workshop agreed to teach the curriculum during the 2013-14 school year, and to give their students pre- and post-knowledge surveys to evaluate the effectiveness of the curriculum.

Bringing current, relevant research into the classroom can be a complicated task, particularly when integrating multiple disciplines. However, a lesson focused on a single disciplinary perspective would not reflect the complexity of real-life applications and would be less relevant to students. Interdisciplinary work has enabled this team to view the world from different perspectives and to communicate research in a way that is relevant to each respective discipline as well as to larger audiences. Not only is integrating real-world science and management tools into the science classroom beneficial for the students and teachers that use the unit, but its development is also beneficial for early-career researchers.

The push for STEM education and the implementation of NGSS at the state and national levels requires new practices and activities in science curricula. The unit attempts to ease this transition by incorporating relevant interdisciplinary science together with physical and computer-based models in a simple format that teachers can implement in their classrooms. Addressing challenges related to implementing the NGSS is a pivotal first step toward changing science education in the United States and better preparing the workforce of tomorrow.

Figure 3. *Two members of the interdisciplinary team, Chelsea Walsh and Hillary Davis, demonstrating the Soil Infiltration and Runoff lab activity. Photo by Brad Stokes.*

STEM education: Science, technology, engineering, and math

Dianne Daley Laursen UI (diannedl@uidaho.edu) and Kristy Borrelli UI

Research, education, and extension are viewed by the U.S. Department of Agriculture's National Institute of Food and Agriculture (USDA NIFA) as three equal and essential parts of the value proposition that is transforming agriculture. One of the strategic goals of USDA NIFA is to develop human and intellectual capital. To support this goal, the REACCH education team is working to introduce innovative agricultural approaches to climate change mitigation and adaptation into K-12 curricula to prepare citizens and professionals for climate-related challenges and to define agriculture's role in providing food, energy, and ecosystem services. As Diogenes once said, "The foundation of every state is the education of its youth." In the past year, REACCH hosted three science, technology, engineering, and mathematics (STEM) education events with lab, field, and classroom activities, assisting many youth on the path of lifelong learning.

IMPACT

Science, technology, engineering, and mathematics (STEM) education focused on agricultural sciences is a key building block to training future scientists and informed consumers that will help ensure sustainable food systems into the future. It is imperative in our region to understand the impacts of climate change, so that regional producers will continue to be a strong economic driver in our communities.

If we teach today's students as we taught yesterday's, we rob them of tomorrow.
—John Dewey

Figure 1. *Chelsea Walsh demonstrates the importance of crop residue in protecting soil from erosion and loss through a simple simulation. Photo by Stephen Cole.*

Washington State University Leadership Development Camp

REACCH participated in a week-long camp for 40 middle and high school students, ages 13 to 15, from the Coeur d'Alene Tribe. Coeur d' Alene land is located in the major wheat-producing region of the ID panhandle.

The REACCH team discussed crops, soils, and the importance of conservation to farming systems. The students learned how parts of a cropping system build on and affect one another in a hands-on soil erosion simulation and in a discussion about cropping systems. Comparing the economic impact of erosion on wheat yields under different scenarios proved to be impactful, as one student exclaimed, "$35,000 lost! That's enough to buy a new car!" A soil erosion demonstration using simple bread pans, water, and crop residue to simulate erosion in the field further strengthened the students' understanding of erosion (Figure 1).

REACCH was joined by Jim Kackman, Coeur d'Alene Tribe public works director and the tribal farm manager. Jim familiarized the kids with maps of the tribe's farmlands, pointing out specific regions where their families farmed. He introduced them to equipment used on the farm and discussed the tribe's efforts to improve conservation using precision management. The students realized that they are stakeholders in their own land. Pride in home and culture is a key component to understanding and appreciating conservation.

University of Idaho Living Systems Class

Budding scientists were busy and engaged as REACCH cohosted 55 students from Moscow, ID, in fourth to eighth grade, introducing them to innovative ways engineers use science to solve problems. Twenty-seven UI students in the Introduction to Living Systems class designed eight science engagement activities that challenged students to think creatively about engineering design and solutions, including activities involving solar ovens, hydropower, wind energy, biofuels, water filtration, prosthetic leg design, precision agriculture, and the use of microorganisms in engineering. The precision agriculture session demonstrated an unmanned aerial vehicle (UAV) and GPS navigation system. The activity not only benefited the elementary school students, it challenged mostly freshman-level college students to come up with creative ways to communicate science to a younger audience, and to define for themselves what it truly means to be an engineer/scientist (Figure 2). At the end of the field trip, 75% of the students raised their hands when asked if they wanted to go into science and engineering when they grow up. A successful day indeed!

University of Idaho HOIST: Helping Orient Indian Students and Teachers

Sixteen Native American high school students interested in pursuing their higher education in a STEM field resided at the

I hear and I forget. I see and I remember. I do and I understand.
—Confucius

Figure 2. *Erin Brooks and University of Idaho student Joel Wilson watch while two seventh-grade students compare the effectiveness of various water filter designs. Photo by Bill Loftus*

University of Idaho this past summer. REACCH organized a science communication thread for all of the students, in which they blogged weekly about their individual STEM experiences. Additionally, each student identified a professional mentor and created a career path video to be posted online so that other students could learn more about STEM careers.

REACCH hosted five of these students for a comprehensive four-week study of the integrated science needed to help create resilient farms that are ready for the future. Themes for the first three weeks included pests, weeds, and beneficials; cropping systems; and monitoring and modeling. Each day the HOIST students were mentored by a different REACCH scientist and graduate student, with total exposure to more than 25 of the REACCH team members, enriching their integrative science learning. Students garnered lab, classroom, and field experience. The HOIST students tested REACCH high school curriculum units under development and will go back to their respective science classes at their home high schools and teach the unit to others, with a total potential impact of 550 students exposed to the REACCH curriculum. Idaho Public Television monitored the summer program and plans to use REACCH material in an upcoming science program for middle and high school students. All the students self-reported that their understanding of climate science, agriculture, and cereal-production systems greatly improved over the summer and said they would gladly participate again.

Equipped with his five senses, man explores the universe around him and calls the adventure Science.
—Edwin Powell Hubble

Figure 3. *Dave Huggins in the field with HOIST students studying soil health.*

Interactive learning modules for climate change education

Laurie Houston (laurie.houston@oregonstate.edu) OSU and Jianhong Mu OSU

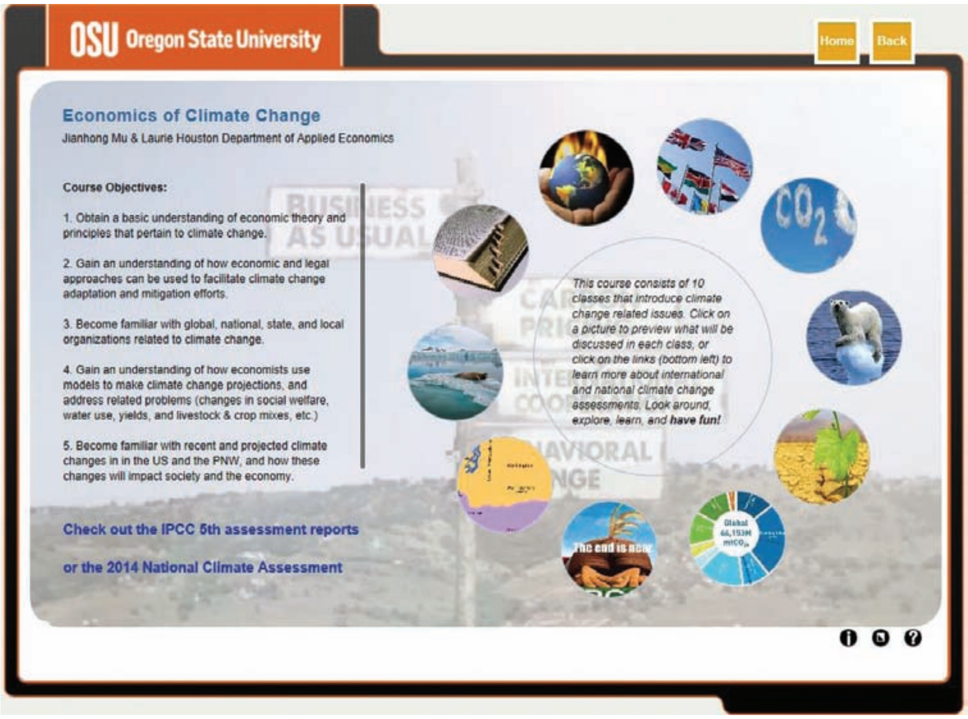
REACCH researchers on the economics and social research objective team are working with Oregon State University (OSU) Ecampus to deliver climate change information through flexible online learning modules. The goal is to help individuals understand the physical facts of climate change, the potential impacts, and possible adaptation and mitigation strategies from an economic and policy perspective. One learning module has already been developed with software called Pachyderm. Pachyderm is a multimedia-authoring software tool that allows for the incorporation of audio, video, text, and images into presentations. The module we created, titled "Economics of Climate Change," provides an overview of climate science and the role economics can play in climate change. It consists of 10 templates with dozens of videos that contain summary information about global and regional impacts of climate change on natural resources such as water, oceans, forests, and agriculture, as well as potential economic impacts. It also includes information on the physical science of climate change, mitigation and adaptation strategies and practices, and key vulnerabilities for the Pacific Northwest (PNW).

IMPACT

The climate change learning module described here, as well as the additional modules currently being developed, provide educators, the general public, and farmers with an easily accessible opportunity to learn about climate change and what it means for the PNW. The modules are being designed to highlight impacts for the PNW, draw attention to mitigation practices that farmers and others can partake in, and explain public carbon policies such as carbon taxes and cap-and-trade programs.

One advantage of using Pachyderm is that it allows the user to obtain information in a nonlinear format, based on his or her interests, and the videos and pictures create an interactive learning environment. Take the opening screen of this module as an example (Figure 1). It presents the course objectives on the left and has 10 nodes on the dial to the right. Users can mouse over each node to get a description of the topics covered and choose which they are most interested in learning about. Then, through videos and short text summaries, they can learn about greenhouse gas accumulation in the atmosphere, or the impacts of a warming globe, or the role economics can play in helping society mitigate and adapt to climate change. The order in which order they choose to review the material doesn't particularly matter.

Another advantage of Pachyderm is the variety of templates and formats it offers for presenting information. For example, in Figure 2, the user sees a video in the center of the screen with a few lines of text above it. Only a portion of the text can be seen, and additional text can be viewed by scrolling. There are also links within the text to reports that can be viewed for more detailed information on a particular topic. Six icons—three on either side of the video—indicate more topics. When the user clicks one of these icons, the video in the center changes to one related to the topic listed, and the text above the video changes accordingly. In each template, users can choose topics they want to learn about in any order they prefer, and information is presented in visual, audio, and text format, to accommodate a variety of learning styles.



Economics of Climate Change

Jianhong Mu & Laurie Houston Department of Applied Economics

Course Objectives:

1. Obtain a basic understanding of economic theory and principles that pertain to climate change.

2. Gain an understanding of how economic and legal approaches can be used to facilitate climate change adaptation and mitigation efforts.

3. Become familiar with global, national, state, and local organizations related to climate change.

4. Gain an understanding of how economists use models to make climate change projections, and address related problems (changes in social welfare, water use, yields, and livestock & crop mixes, etc.)

5. Become familiar with recent and projected climate changes in in the US and the PNW, and how these changes will impact society and the economy.

Check out the IPCC 5th assessment reports

or the 2014 National Climate Assessment

This course consists of 10 classes that introduce climate change related issues. Click on a picture to preview what will be discussed in each class, or click on the links (bottom left) to learn more about international and national climate change assessments. Look around, explore, learn, and ***have fun!***

Figure 1. *The opening screen of the "Economics of Climate Change" learning module outlines the course objectives and contains a dial with links to 10 learning module templates.*

Overview of Climate Change Issues

What does economics have to do with climate change?

Climate change is a global issue with many environmental and economic consequences. This class will provide a review of the causes of climate change, the sources of greenhouse gasses, how the climate has changed in the 20th century, expected changes in the future, how climate change will impact our economy, and policies and regulations that can and are being implemented to

What is climate change and how does it relate to economics?

Are we responsible for climate change?

How has climate changed?

What climate conditions can we expect in the future?

Mitigation and adaptation

Greenhouse Gas Emissions

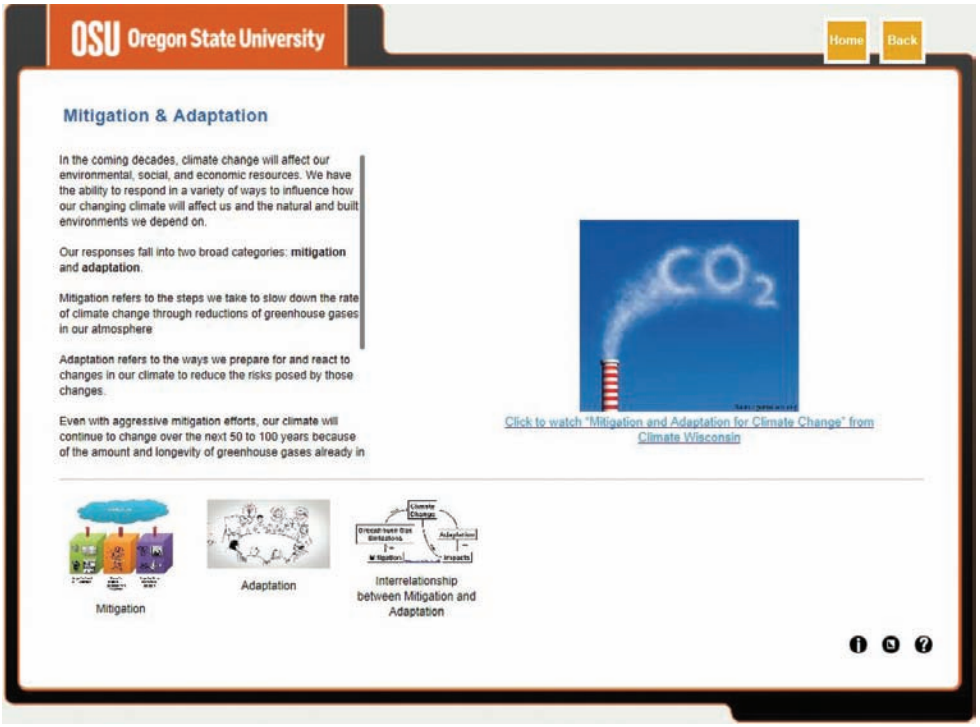
Click on the video to watch "Climate Change: an Economic Solution?

Figure 2. *Example of a Pachyderm learning module template. Clicking one of the six images to the left or right presents the user with a new video and text in the center of the screen.*

The module is available online at http://osupachyderm.org/pachyassets/presos/ClimateChangeCourse299/index.html#screen/00-128-638510300555-12810016112710563579347-17-13 and can also be downloaded to mobile devices to be viewed with or without Internet access. It was developed to be used with an introductory-level climate change economics course currently being created by U.S. Department of Agriculture National Needs Graduate Fellows at OSU. The REACCH extension team can also use the module as a learning tool as they present climate change materials to the general public. They can choose particular portions of the module to highlight the subjects they are presenting. Incorporating the recently developed Farmer-to-Farmer Case Study videos produced by REACCH into the adaptation and mitigation portion of the module would also be a great way to share the innovative practices of some of our PNW growers, such as precision nitrogen applications, cover cropping, flex cropping, and enhancing crop diversity.

Pachyderm does present some limitations. For example, it is primarily visual, so there is not much room for explanatory text. Also, some templates, such as the one in Figure 3, have plenty of room for text and pictures but are not designed to accommodate an embedded video. In those instances, one is forced to provide a link to an online version of the video rather than embedding the video within the learning module, thus limiting the usefulness of the module when the Internet is not available. Some users may also get confused as to how to return to the leaning module or may be distracted by other videos offered on the external video website.

We are currently working with Open Oregon State to develop a similar online learning module that will have much of the same content without the limitations imposed by the Pachyderm software. This format will allow more interactive activities, such as incorporating thought-provoking questions and summarizing key video content after it has been viewed. These creative learning modules, whether they are developed using Pachyderm or with other software, provide a new way for people to learn about and understand climate change within a flexible, interactive, and interest-oriented learning experience. Most importantly, they are easily accessible online and are germane to a broad audience, be it high school students, the general public, or for use in college courses



Mitigation & Adaptation

In the coming decades, climate change will affect our environmental, social, and economic resources. We have the ability to respond in a variety of ways to influence how our changing climate will affect us and the natural and built environments we depend on.

Our responses fall into two broad categories: **mitigation** and **adaptation**.

Mitigation refers to the steps we take to slow down the rate of climate change through reductions of greenhouse gases in our atmosphere

Adaptation refers to the ways we prepare for and react to changes in our climate to reduce the risks posed by those changes.

Even with aggressive mitigation efforts, our climate will continue to change over the next 50 to 100 years because of the amount and longevity of greenhouse gases already in

Click to watch "Mitigation and Adaptation for Climate Change" from Climate Wisconsin

Mitigation

Adaptation

Interrelationship between Mitigation and Adaptation

Figure 3. *This template has links to an online video, an online report, and other subtemplates accessible by clicking the images at the bottom of the screen.*

Graduate students are the nitrogen for growing REACCH's research

Edited by Leigh Bernacchi (lbernacchi@uidaho.edu) UI

REACCH graduate students are poised to be the leaders of research, extension, and education for the future of agriculture and climate change. As with most programs, they have trained within their disciplines, mentored by their major professors, Principal Investigators (PIs) on the REACCH project, to be adept at understanding and solving problems within their paradigm. Where REACCH students have gone above and beyond is in connecting through their objective teams and throughout the project to create enriching and creative representations of research, to meet multiple stakeholders through effective communication at field days, in classrooms, and in online videos, and to prepare for the greatest challenges yet to come.

IMPACT

Graduate students are at the core of our research program: they collect and analyze data, present their research to a wide variety of stakeholders, and serve as an interdisciplinary bridge through their extension and education projects. Most importantly, with their breadth and depth of knowledge, they will be the future leaders of climate change adaptation and agricultural sustainability.

"Post-docs," PhD students, and master's students share in one another's accomplishments, and as we stride toward the end of the project, there is only more to celebrate: more defenses, graduations, grant awards, and jobs.

Mukhtar Ahmed (mukhtar.ahmed@wsu.edu) WSU
Postdoctoral researcher, advised by Claudio Stockle
Multimodel approach to study the impact of climate variability on the productivity of wheat systems

As part of REACCH, we are using computer models to conduct a regional assessment of yields, water, and carbon footprint for baseline and future climatic conditions . We use gridded daily weather data (2.49×2.49 miles, 4x4 kilometers) for the period 1979 to 2010 and, for future weather, daily data projected by 14 global climate models (GCMs) for two representative concentration pathways (RCPs) of atmospheric carbon dioxide (CO_2) (4.5 and 8.5 parts per million), for a total of 28 future weather scenarios. An ensemble of five wheat growth models extracted

REACCH Scientific Advisory Panel (SAP) members (back row left) Karen Garrett, University of Florida new preeminence faculty in plant diseases, Phil Robertson, Distinguished Professor of Ecosystem Science at Michigan State University Kellogg Biological Station, and Senthold Asseng, University of Florida Department of Agricultural and Biological Engineering, with graduate students at the REACCH annual meeting in Richland, WA. Students discussed professional goals and research collaborations.

from CropSyst, APSIM-Wheat, CERES-Wheat, STIC, and EPIC are being coded to run under the platform of CropSyst. This platform will provide input/output operations and scenario creation capabilities (weather, soils, crop rotations, management) and will simulate hydrologic processes, including all components of the water balance, and nutrient cycling. The main objective of this multimodel study is to reduce the uncertainty associated with individual wheat growth models. Preliminary evidence has shown that the use of ensembles of crop growth models can be an effective way to reduce uncertainty.

Liz Allen (lizb.allen@wsu.edu) WSU
PhD candidate, advised by Chad Kruger
Stakeholder engagement in environmental model development and science communication

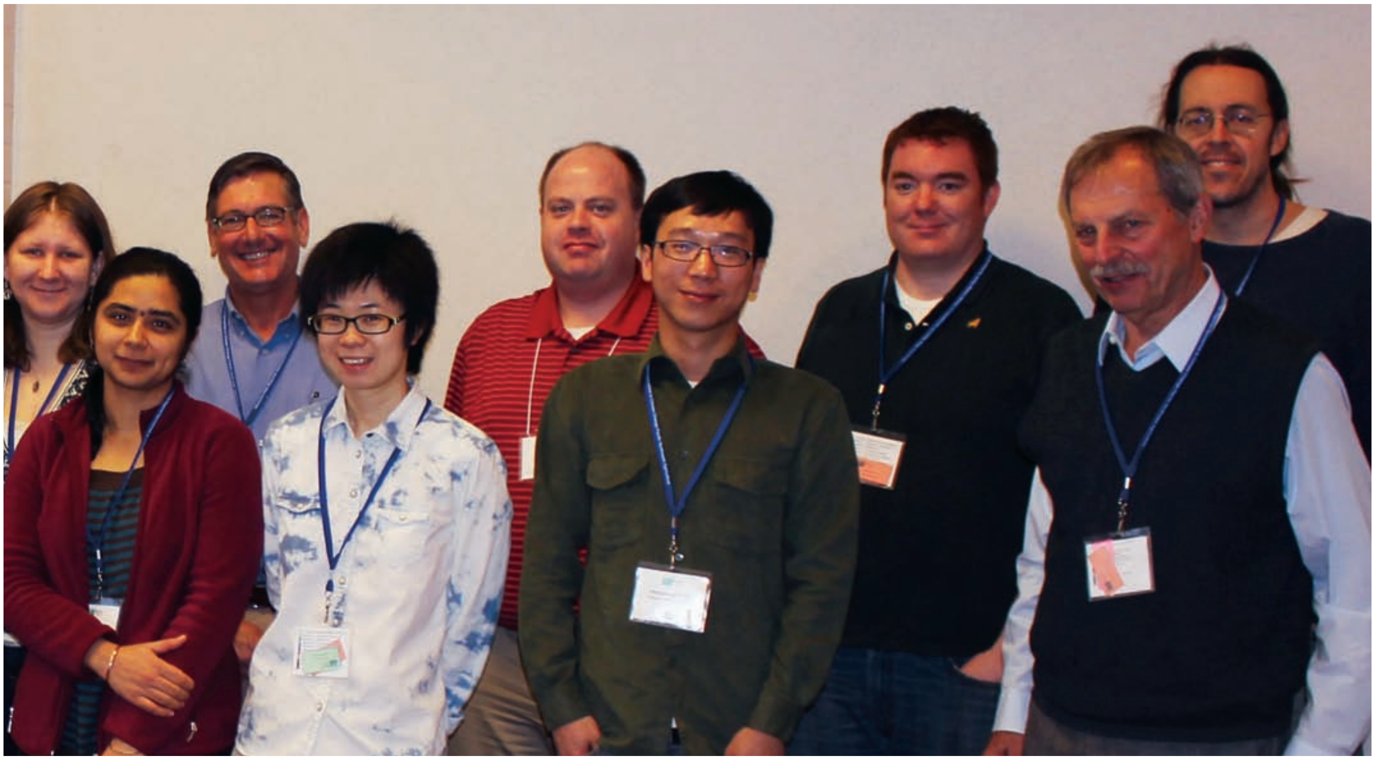
My primary work is as a member of the communication and extension team of the WSU-based BioEarth regional earth systems modeling project. Within BioEarth, I'm involved in the design and evaluation of stakeholder engagement strategies. The BioEarth model will link hydrological, atmospheric, vegetation, and social/economic models, with the aim of producing outputs that are relevant to the needs of regional decision makers, especially in the agriculture and forestry sectors. We are looking at how scenario planning tools can use stakeholders' input and are tracking learning among researchers and stakeholders engaged in the research project. A key component of this research involves comparing approaches to interdisciplinary collaboration and stakeholder engagement across multiple regional-scale projects, including REACCH.

Iqbal Singh Aujla (iqbal.aujla@email.wsu.edu) WSU
PhD candidate, advised by Tim Paulitz
Impact of climate change on foliar and soil-borne pathogens of wheat in the Pacific Northwest region

Crops yields are affected to a large extent by diseases caused by various pathogens. Climate change will affect not only the distribution patterns of the fungal pathogens, but also their severity, depending upon the requirements of the fungi for soil moisture levels and temperature. Soil-borne fungi can actively grow and infect plants only when soil moisture is adequate and temperatures are optimum. Under extremely dry, cold, or hot conditions, fungi cease to grow and form resistant structures to survive until conditions are suitable. Thus, changes in climate may have a profound effect on the distribution of fungal diseases. The focus of this study is to analyze the impact of climate change on the distribution patterns of both foliar and soil-borne fungal pathogens of wheat in the Pacific Northwest (PNW) region.

Taylor Beard (taylor.beard@email.wsu.edu) WSU
Master's student, advised by Bill Pan
Introducing canola as an alternative crop in the Pacific Northwest

The main goal of my research as a graduate student was to understand the potential of canola and wheat residues to resist degradation and affect soil crusting. Arid and semiarid agronomic regions that have adopted



REACCH graduate students with SAP members, Matt Baker Dean of University College Texas Tech University (back second from left) and Richard Howitt (front right), University of California Davis, Professor emeritus agricultural and resource economics. Photo by Leigh Bernacchi.

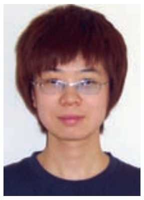
conservation management practices, such as reduced tillage, may be prone to soil crusting. Crusting can reduce water infiltration, enhance runoff and erosion, and interfere with seed germination. Structural components (e.g., hemicellulose, cellulose, lignin, and silicon (Si)) vary among crop types. Grasses such as wheat tend to have higher levels of Si and lower amounts of lignin when compared to oilseeds. When such residue is left on the soil surface, these components, specifically Si, may contribute to soil crusting. Therefore, it may be beneficial to consider crops with lower amounts of Si when planning rotations in areas where soil crusting can be an issue.

Leigh Bernacchi (lbernacchi@uidaho.edu) UI
Postdoctoral researcher, advised by J. D. Wulfhorst
Capacity for the public and wheat producers to respond to climate change
We surveyed wheat producers of the REACCH study area counties by mail and residents of ID, OR, and WA by phone on their perceptions of climate change, including risk and adpatation, and agriculture. Significant findings show that the general public has observed changes in weather over their lifetime (83%), but more than half of them attribute these changes to natural causes. Agricultural producers show varied levels of adaptability, depending on their current cropping practices: some have already adopted conservation tillage, and these are least likely to change their tilling again. The findings have implications for local planning and management by elucidating barriers and opportunities to effective climate adaptation and mitigation as well as community sustainability.

Prakriti Bista (prakriti.bista@oregonstate.edu) OSU-CBARC
Postdoctoral researcher, advised by Stephen Machado
Agronomic performance of cropping systems and crop modeling
I study cropping systems that promote biologically productive, economically profitable, and environmentally sound production practices. In the Pacific Northwest (PNW), the increasing climatic variability and degradation of soil resources have influenced crop productivity. Specifically, the loss of soil carbon and nitrogen in the form of greenhouse gases has influenced agricultural system sustainability in this region. My postdoctoral research involves monitoring and modeling the effect of traditional and conservation management practices on the agronomic performance and soil organic matter dynamics of dryland wheat-fallow systems in the Pacific Northwest. I am also evaluating the effect of cover crops on wheat yield, and on soil organic carbon and total nitrogen. I am involved in various types of extension work, including preparing a conservation handbook and helping write the State of the Region report.

Ryan Boylan (rboylan@uidaho.edu) UI
Master's student, advised by Erin Brooks
Modeling and monitoring sediment and nutrient transport from agricultural watersheds
Mitigation strategies to minimize the loss of soil carbon require a fundamental understanding of the dominant hydrologic flow paths, which drive runoff generation, soil erosion, and ultimately the quantity and quality of carbon exported from a landscape. We quantified temporal and spatial hydrologic carbon fluxes at three watershed scales (~10 hectares, ~25 acres ~5,000 hectares, ~12,355 acres; and ~900,000 hectares, ~2,223,948 acres) and under two tillage practices (conventional and no-till), using the Water Erosion Prediction Project (WEPP) model to simulate present and future field-scale variability in runoff and soil carbon erosion from a ~10-hectare field catchment managed under conventional tillage practices. Dissolved organic carbon concentrations were two times greater from the no-till catchment, while total organic carbon loads were 97% less than those observed at the conventional till catchment. Future climate predictions with the WEPP model indicate that sediment and loads will be equivalent to historic levels (>20 milligrams per hectare) and slightly higher than current rates for runoff and carbon.

Tabitha Brown (tabitha_brown@wsu.edu) WSU
PhD candidate, advised by Dave Huggins
Impact of agricultural management practices on soil health, productivity, and nutrient use efficiency
Site-specific nitrogen fertilizer management has been reported as an important strategy to increase nitrogen use efficiency (NUE) in modern cropping systems. The Palouse region of eastern WA is characterized by complex soil fertility and crop productivity patterns, but cropping systems are typically managed uniformly. The overall research goals were to investigate relationships among winter wheat (*Triticum aestivum*) yield, water, and NUE across landscape positions that differ in soil properties and historical yield. I determined NUE components and indices based on soil and crop physiology and used them to develop performance classes for winter wheat to aid in site-specific nitrogen fertilizer and seeding rate management decisions for the region.



Jinshu Chi (jinshu.chi@wsu.edu) WSU
PhD student, advised by Shelley Pressley
Assessments of carbon and water dynamics in agriculture using eddy covariance
Global food demand is predicted to increase 100% by 2050, thereby increasing demands from ecosystem services, including agricultural production and natural resources. Future climate projections for the inland Pacific Northwest show a likely increase in temperature and significant reductions in precipitation that will affect carbon and water dynamics. This new scenario requires a comprehensive understanding of impacts of climate and management practices on carbon and water dynamics in agricultural ecosystems. My research mainly focuses on measurements of carbon and water fluxes using eddy covariance methods in the inland PNW region, in order to determine the best management practices for sustainable agriculture in the region in the future.

Seth Davis (thomasd@uidaho.edu) UI
Postdoctoral researcher, advised by Sanford Eigenbrode
The chemical and microbial dimensions of plant-insect interactions
I am investigating how environmentally mediated "ecological switches" drive disease dynamics in cropping systems, with efforts aimed at developing ecological models to describe how context-dependent pathogen-vector-host interactions promote pathogen retention in the landscape. I employ behavioral ecology and plant physiology approaches to investigate how aphid-vectored viruses mediate the response of plants to environmental stress. I have developed tractable methods for asking novel questions about the ecological drivers of pathogenesis, discovering that the consequences of virus infection for host plants span the pathogen-mutualism continuum relative to water availability. I am especially interested in elucidating the pathways by which elevated environmental stress may drive the origin of mutualistic interactions in pathosystems. Ongoing hypothesis testing is aimed at identifying an inheritable biochemical basis underlying plant responses to interactions between water availability and viruses in greenhouse and common garden experiments.

Hilary Donlon Davis (hilaryd@uidaho.edu) UI
Master's student, advised by Kate Painter
Longitudinal survey of wheat growers in the inland Pacific Northwest
This longitudinal survey is a four-year survey of growers and their wheat production practices, collecting information for the crop years 2011 to 2014. The survey is used to inform REACCH scientists about production practices in the four agroecological zones (AEZs). Data from this survey cover topics ranging from insects to economics. The survey collects the economics of each grower, and my primary focus is to compare economic variables between the AEZs. For each participant in the survey, an economic budget was made for each year of collected data. Another output from this collected data will be extension enterprise budgets for the three dryland AEZs.

Paige Farrell (farr8438@vandals.uidaho.edu) UI
Master's student, advised by John Abatzoglou
Climate change impacts on soil erosion in the inland Pacific Northwest
I used the Water Erosion Prediction Project (WEPP) model, which can account for various cropping practices, soil profiles, and geomorphology, to examine the potential impacts of climate change on soil erosion. I performed several sensitivity experiments to estimate the change in erosion due to changes in temperature, precipitation, and precipitation intensity. In addition to these sensitivity experiments, I applied downscaled data from climate projections to WEPP modeling and examined the projected impacts across the inland Pacific Northwest. These experiments will assist land management by identifying future erosion risks in a changing climate and potential efforts to mitigate detrimental impacts by modifying agricultural and land use practices.

Wenlong Feng (feng6701@vandals.uidaho.edu) UI
Master's student, advised by John Abatzoglou
Relationship between climate and winter wheat yields in the Columbia Basin
There is strong interannual variability in wheat yields across the Pacific Northwest that are spatially coherent, suggestive of large-scale climate drivers. In the moisture-limited area in the western Columbia Basin, cool-season precipitation positively correlated with wheat yield. In the eastern portion of the basin, growing degree days positively correlated with wheat yield. Spring to midsummer potential evapotranspiration had a significant negative relationship with wheat yields in the central portion of the basin, with insignificant or even positive correlation to wheat yields in areas with sufficient moisture. The July Palmer Drought Severity Index strongly correlated with wheat yields in most water-limited counties in the study region, suggesting a strong link between drought severity and wheat yield. These correlation coefficients between climate and wheat yields may supplement the process-based models to offer yield forecasts related to climate variation.

Edward Flathers (flathers@uidaho.edu) UI
PhD candidate, advised by Paul Gessler
Ecoinformatics—Data science
One of the challenges of modern science is being able to consume the deluge of different kinds of data coming from a multitude of sources and organize those data for analysis. My research is focused on collecting, managing, and analyzing "big" data using novel computational, statistical, and visual techniques. I emphasize open science methodology: publication of research data, computer code, and other materials that explicitly enable reuse and repeatability of research methods. By combining data that are produced though remote sensing systems such as satellites and aircraft, local monitoring systems such as flux towers and weather stations, field observations collected by people, and other sources, we can develop a more complete understanding of the world around us and the processes that make it work.

Nathaniel Foote (foot2969@vandals.uidaho.edu) UI
Master's student, advised by Sanford Eigenbrode
Interspecific competion among cereal aphids as influenced by drought
The aphid *Metopolophium festucae* subsp. *cerealium* (MFC) is a recent invader in the Pacific Northwest (PNW) and has become an established pest attacking small-grain cereals throughout the Palouse. Potentially affecting its spread and pest status in the region are competition with other cereal aphid species, as well as certain climate-related factors that affect the insect herbivore community as a whole. We are using an experimental approach that employs a series of greenhouse studies to determine whether MFC actively competes with the historically established bird cherry-oat aphid (*Rhopalosiphon padi*), and whether water limitation of their shared host plant, wheat (*Triticum aestivum*), can alter the outcome of this competition. We aim to improve understanding of competitive interactions among co-occurring insect pests of cereal grains under projected

climate scenarios, in which drought may become a more prevalent condition affecting agriculture in the PNW.

Rajan Ghimire (Rajan.Ghimire@oregonstate.edu) OSU-CBARC
Postdoctoral researcher, advised by Stephen Machado
Soil organic matter dynamics in dryland cropping systems

Loss of soil organic carbon (SOC) and nitrogen from agroecosystems is a major challenge in sustainable crop production. Climate change and variability has posed additional challenges to agronomic, economic, and ecological efficiency of existing management practices. I am evaluating long-term trends in SOC, nitrogen, and crop yields, and monitoring seasonal and interannual dynamics of labile (less than a year turnover time) SOC and nitrogen pools in existing long-term experiments, as well as in recently established experiments. Addition of organic residue, including legume crops in rotation, and minimum soil disturbance increases SOC accrual and improves sustainability of winter wheat-based production systems in this dry region. Pendleton long-term experiments provided a great platform to understand the impact of historic changes in management practices, technologies, and production environments to shape the present-day agriculture and to postulate the future trends of dryland farming in the PNW.

Katherine Hegewisch (khegewisch@uidaho.edu) UI
Postdoctoral researcher, advised by John Abatzoglou
Statistical downscaling of global climate models

Global climate models (GCMs) are the primary tool used by regional planners to assess future climate impact on agriculture. Downscaling is the process of generating locally relevant data from the GCMs. I have downscaled outputs from 20 GCMs of the fifth phase of the Coupled Model Intercomparison Project (CMIP5), using two representative concentration pathways (RCP 4.5 and RCP 8.5), for the contiguous United States and for several meteorological variables (tasmin, tasmax, rhsmin, rhsmax, pr, rsds, uas, vas) for 1950 to 2099, using the Multivariate Adaptive Constructed Analogs (MACA) statistical downscaling method. These data can be accessed through either the REACCH data portal or the Northwest Knowledge Network (see http://maca.northwestknowledge.net). I have refined the original MACA method for better performance in correcting for biases inherent in climate models. The MACA data have been used by both REACCH teams and other organizations throughout the PNW for studying future hydrology , vegetation, and agricultural crops.

Jocelyne Helbling (jhelbling@vandals.uidaho.edu) UI
Master's student, advised by David Meyer and John Anderson
Social network analysis of interdsiciplinarity

Networks are implicit in a wide range of phenomena, including the social, biological, and physical. Network behavior is informal socializing that subtly reaffirms social and cultural values. Network analysis is a systematic, interdisciplinary methodology that uses empirical, mathematical, and computational approaches to measures and assess relational patterns across a broad range of individuals, groups, or entities to understand how interactions between individuals or entities give rise to large-scale patterns. These patterns can be seen in the overall structure of the network and in the emergent behaviors that characterize the system as a whole.

Tina Karimi (tina.karimi@email.wsu.edu) WSU
PhD student, advised by Claudio Stockle
Simulation of regional yields and greenhouse gas emissions under climate change in the Pacific Northwest

Using the CropSyst cropping systems simulation model and daily weather data, we downscaled to a 2.49-square-mile (4-square-kilometer) grid to assess the impact of possible climate change and management scenarios that cannot be experimentally evaluated. We considered typical conventional tillage and alternative conservation tillage practices for each zone. With this simulation setup, my research will evaluate (1) wheat production in Pacific Northwest drylands, soil water content (by considering water budget components), and nitrogen budget components, and (2) long-term soil organic carbon changes, nitrous oxide emissions, and total carbon footprint through life cycle assessment analysis, for current and future climate conditions by considering all scenarios in three agroecological zones.

Harsimran Kaur (harsimran.kaur@email.wsu.edu) WSU
PhD student, advised by Dave Huggins
Predicting for important bioclimatic variables for REACCH agroecological zones

Land use classification studies often rely on biophysical variables hypothesized to be key drivers or determinants of land use/cover. Weak relationships, however, can occur between delineated land use classification and actual land use. In contrast, classification based on land use/cover that has emerged as a consequence of determinants may be advantageous, as the actual land use can then be used to select important driving variables. Our expectation is that this approach can better select for those variables that have a major effect on the actual land use, and therefore, that the selected variables can eventually be used to predict future land use under different climate change scenarios.

Kedar Koirala (kedar.koirala@email.wsu.edu) WSU
PhD student, advised by Dave Huggins
Environmental air quality, environmental data analysis

A recent addition to REACCH, I will be conducting data analyses for the Cook Agronomy Farm to answer questions on precision agriculture such as spatial and temporal variability of crop yields. These analyses will aid the science-based development of field management zones relevant to precision agriculture.

Nevin Lawrence (nevin.lawrence@wsu.edu) WSU
PhD candidate, advised by Ian Burke
Variation in downy brome development in the small-grain production region of the Pacific Northwest

Due to climate change, the Pacific Northwest PNW is projected to experience more frequent mild winters, which may speed up the development of many weed species compared to current observations. Enhanced knowledge of weed response to recent climatic trends can help growers adapt to climate change, and an understanding of the biological response in weed species could be used as an indicator of realized adaptation and climate change. I've chosen to assess the physiological and ecological response of *Bromus tectorum* L. (downy brome) to climate change. A current pest within the small-grain production regions of the PNW, downy brome is likely to remain a major weed of small grains in the region as the climate changes in coming decades.

Kirill Kostyanovsky (kirya.kostyanovsky@wsu.edu) WSU
Postdoctoral researcher, advised by Dave Huggins and Claudio Stockle
Seasonal and diurnal dynamics of N_2O and CO_2 emissions in no-till winter wheat systems in the Pacific Northwest

My research within the REACCH scope is on in situ instrumentation and monitoring of soil nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions with the static chambers via a portable flow-through system. We analyze isotopes of N_2O to discover the sources of N_2O emissions within the soil nitrogen cycle. The focus of my research is N_2O and CO_2 production in tillage and no-till wheat-based cropping systems, effects of dry-wet cycling and nitrogen application on N_2O emissions, and seasonal dynamics and the effects of freeze-thaw events. Another aspect of my research is quantification of availability, transport, and the effects of nitrogen and organic matter on net N_2O and CO_2 emissions.

Sihan Li (sli@coas.oregonstate.edu) OSU
PhD candidate, advised by Philip Mote
Superensemble regional climate modeling for improved projections

I have been working on a superensemble of regional climate modeling for the western United States, as part of a citizen science experiment called climateprediction.net. We use computer time contributed by tens of thousands of volunteers around the world to create superensembles to perform regional climate modeling. I am looking at the dominant model parameter changes and how they relate to the major regional scale prognostic variables; that is, I am trying to relate the macroscopic variation in regional climate response to the subgrid scale parameterization. To fully deal with uncertainties in regional climate modeling, the systematic bias—that is, irreducible error—must be considered directly within the analysis. By thoroughly looking into and quantifying different sources of uncertainties in regional climate modeling, we can make more meaningful and accurate projections of the future climate.

Tai McClellan Maaz (tai.mcclellan@wsu.edu) WSU
PhD candidate, advised by Bill Pan
Nitrogen use efficiency and cycling in no-till cropping systems that feature canola, peas, and wheat

Indigenous soil nitrogen supply is often not factored into nitrogen use efficiency (NUE) equations, despite its large contribution to plant nitrogen nutrition and its role in nitrogen cycling. My research includes greenhouse, laboratory, and field experiments to determine (1) differences in soil nitrogen uptake and partitioning in wheat (*Triticum aestivum* L.), field pea (*Pisum sativum* L.), and canola (*Brassica napus* L.) and (2) the effects of crop and fertilizer on net nitrogen mineralization and nitrogen carryover. In laboratory studies, I have linked the partitioning of carbon and nitrogen into structural and soluble cell components to the effects of crop residues on soil mineralization/immobilization potential. Findings from my field study have related residual nitrogen carryover and crop residue nitrogen to the availability of nitrogen for subsequent crops, with multiyear nitrogen balances capturing the effects of fertilization and the inclusion of legumes on rotational NUE. My research will help inform growers participating in the expansion of canola production within WA's wheat-based cropping systems.

Isaac Madsen (isaac.madsen@email.wsu.edu) WSU
PhD student, advised by Bill Pan
Nitrogen loss from irrigated cropping systems

Research conducted at the Irrigated Agricultural Research and Extension Center in Prosser, WA, is designed to examine the impacts of cover cropping and reduced tillage on nitrate soil profiles in a potato-corn-wheat rotation. Potato, corn, and wheat are field crops often grown in rotation in the Columbia Basin. Potatoes in particular are intensively managed with high levels of fertilizer and pesticides. Determining the uptake of fertilizers and developing and evaluating conservation practices such as cover cropping and reduced tillage are important aspects of agricultural sustainability in the Columbia Basin. Preliminary data show cover crops reducing nitrate levels in the 2nd, 3rd, and 4th feet.

Troy Magney (tmagney@uidaho.edu) UI
PhD candidate, advised by Lee Vierling and Jan Eitel
Remote sensing of crop structure and function

My research focuses on the development, testing, and application of remote sensing instruments to monitor the temporal, spatial, and mechanistic dynamics of plant structure and function. These remote sensing instruments include ground-based radiometers (reflectance based), LiDAR instruments (laser based), time-lapse digital cameras, and satellites. Using information from these different types of instruments enables the mapping of patterns associated with crop stress, nutrient uptake, and productivity. By looking through different lenses (slices of the electromagnetic spectrum), we can learn new information regarding the wide variability of field productivity to help establish management zones.

John Merickel (meri8103@vandals.uidaho.edu) UI

Master's student, advised by Bahman Shafii

Aphid population modeling

By using the data from the Idaho suction trap network, we can gain a better understanding of the population dynamics of four cereal grain pest aphid species through statistical modeling. We used nonlinear regression models to describe the intraannual accumulation of aphids. We then used climate data to group the 12 Idaho suction trap sites into similar environments through clustering processes. Finally, we developed individual models for each species, specific to each environment, using nonlinear regression and incorporating an autocorrelation structure to model interannual population variation. These models have the potential to help the cereal grain producers of Idaho and the region better forecast aphid populations in order to optimize their harvest yield.

Ashutosh Misra (ashutosh.misra@wsu.edu) WSU

Postdoctoral researcher, advised by Claudio Stockle

Estimation of weather variables for crop growth modeling, risk quantification for crop insurance programs

The vulnerability of agriculture to weather and climate fluctuations makes these fluctuations an important part of the crop production system, but we usually do not have complete weather time series for crop production modeling. To cope with this, we are trying to identify suitable techniques for (1) parameterizing and evaluating solar radiation, relative humidity, and wind speed as compared to observations using estimated parameters from available neighboring stations and (2) comparing the results of crop growth simulations using observed and estimated weather. The outcome of the study will help quantify risk in different crops, making it useful in designing and developing crop insurance products.

Jason Morrow (jason.morrow@email.wsu.edu) WSU

Master's student, advised by Dave Huggins

The influence of climate and management on surface soil health within the inland Pacific Northwest

Surface soils influence ecosystem health through their role in nutrient cycling and decomposition, gas exchange, water infiltration, and erosion. Soil organic matter (SOM) is critical to soil functioning and subsequently to soil and ecosystem health. Both the hydrolyzable and nonhydrolyzable fractions of soil organic carbon were equally sensitive to climate, indicating no relationship between chemical recalcitrance and climate sensitivity. Permanganate oxidizable carbon (POXC) was representative of SOM stabilization, while one-day carbon mineralization was representative of microbial activity and SOM mineralization. Both POXC and mineralization potential may be increased by cropping diversification, and stabilized inputs such as compost, along with no-till, may increase POXC. Plant-available nutrients displayed varying correlations with soil carbon and nitrogen properties, management, and climate factors. Overall, POXC and carbon mineralization were shown to be important indicators of surface soil health.

Jianhong Mu (jianhong.mu@oregonstate.edu) OSU

Postdoctoral researcher, advised by John Antle

Economics of climate change impacts on crop yields, land use, and agricultural production systems

We modeled adaptation following the way farmers make decisions: short-term allocations (within system) nested within long-term allocations (choices between systems), and found substantial potential for adaptation. Under climate change impacts, cropland, pastureland, and rangeland use could change by 6% to 15%, –2% to 5%, and –14 to –5%, respectively, under a lower-emission scenario (RCP 4.5) and by 5% to 20%, –5% to 5%, and –15% to 3%, respectively, under a high- emission scenario (RCP 8.5). These results show that the effects of climate change could be substantially different under alternative plausible future representative agricultural pathways and scenarios. They indicate the types of uncertainties we need to discuss when assessing climate change impacts.

Byju Nambidiyattill Govindan (byju.ng@wsu.edu) WSU

Postdoctoral researcher, advised by Claudio Stockle and Sanford Eigenbrode

Development of biotic modules for integration into the cropping system model

The cereal leaf beetle (CLB) is one of the pests with the potential to cause increased crop damage with warming temperatures. Elevated temperatures will cause faster developmental rates in insects by increasing their metabolism rates in a nonlinear fashion, increase the winter survival rate of different life stages of pests, disrupt their synchrony of emergence with natural enemies, and increase the risk of damage to crops. Development of a nonlinear temperature-dependent population model is expected to help predict the population growth potential of CLB and link the relative abundance of CLB to the feeding damage potential to wheat under future climate scenarios in the various agroclimatic zones of the PNW. The outcomes from the project are expected to help researchers plan adaptation strategies for integrated pest management in a changing climate and inform policies on global food security.

Lauren Parker (lparker@uidaho.edu) UI

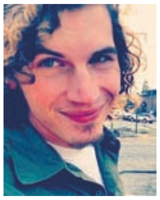
PhD student, advised by John Abatzoglou

Spatial coherence of precipitation extremes

Extreme precipitation events across the PNW, although rare, affect the region by causing increased runoff, flooding, damage to infrastructure, and loss of life and property. Using data from the National Weather Service Cooperative (COOP) and the Natural Resources Conservation Service Snow Telemetry (SNOTEL) stations, I examined three-day precipitation accumulations exceeding the 95th percentile over the past two decades. I used simple metrics to show the relationship between distance and the probability of synchronous occurrence of extremes between station pairs, the regional representativeness of each station, and the preferential direction for coherence. Initial results show that the spatial coherence of extremes between stations decays with distance. The role of Pineapple Express events in producing extreme precipitation exhibits clear spatial patterns across the region, and Pineapple Express storms do result in regional extreme events of both high and low coherence.

Qiuping Peng (qiuping.peng@wsu.edu) WSU
PhD candidate, advised by Dave Huggins
Carbon and nitrogen dynamic and cycling under different crop rotation systems

My research interests are carbon and nitrogen cycling in soil. Monitoring carbon and nitrogen dynamics under different crop rotations and tillage management would show how the soil responds to anthropogenic activities, would offer clues that could lead to practical and meaningful solutions for sustainable agriculture development, and would be beneficial to food productivity and environmental protection.



Alexander Peterson (pete5506@vandals.uidaho.edu) UI
Master's student, advised by John Abatzoglou
Bioclimatic changes in false springs across the United States

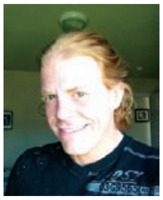
Crop species receptive to thermal accumulation during the spring may break dormancy and begin developing earlier in the year; however, advances in phenological timing may leave early-stage vegetation growth vulnerable to cold damage when hard freezes follow green-up, resulting in a false spring. I modeled spatiotemporal patterns of green-up dates, last spring freezes, and false springs across the contiguous United States from 1950 to 2099, using downscaled climate projections. Results indicate widespread advancement in the timing of green-up and last spring freeze dates over the period, with last spring freezes trending earlier in the year relative to green-up. Although regionally variable, these changes result in an overall reduction in false springs across the United States.

Megan Reese (megan.reese@wsu.edu) WSU
Master's student, advised by Bill Pan
Winter canola water use

Winter canola can introduce diversity into the traditionally winter wheat-fallow rotations of WA's intermediate-rainfall and low-rainfall zones. However, this crop is relatively new, and best agronomic practices are still evolving. I initiated an on-farm winter canola seeding date trial in 2013 in Ritzville, WA. In addition, I established winter canola variety trials in Pomeroy, Asotin, and Okanogan in 2014. At each site, I measure soil water content biweekly via gravimetrically analyzed cores and a neutron probe. In addition, I collect biomass samples. I will quantify nitrogen and water use efficiencies, extraction depths and patterns, and total water usage and relate them to growing degree day progression. Very little research has focused on winter canola water use, and the information garnered from this study has the potential to guide production management decisions.

Seyed Ebrahim Sadeghi (ebrahims@uidaho.edu) UI
Postdoctoral researcher, advised by Sanford Eigenbrode
***Effect of climate change on aphid vectors of* Barley yellow dwarf viruses**

The majority of cereal aphids in the region are vectors for the *Barley yellow dwarf virus* (BYDV). Our objective is to test the hypothesis that this new aphid is a good vector for BYDV (PAV, SGV, and MAV serotypes). After obtaining evidence of BYDV transmission by the aphid, we will study its vector capacity for the virus. Meanwhile, we will compare life table parameters of aphids on healthy and BYDV-infected plants and two different temperatures in controlled chambers.The second priority in my work is to analyze data concerning population densities of different aphid species collected during 2011 to 2014. These data have been collected at 119 collecting sites distributed over 32 municipalities in ID, WA, and OR. The data will be analyzed to find out the relationship between climatic factors and the population density of the aphid species under study.



Erich Seamon (erichs@uidaho.edu) UI
PhD student, advised by Paul Gessler
Ecoinformatics applications for modular scientific investigation

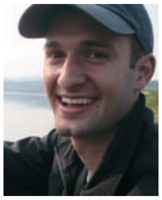
My current research interests are working with geospatially enabled data sets—from metadata organization to analytical tool and data mining techniques. I am currently exploring how evapotranspiration varies in relationship to crop yield for the inland PNW, and how this approach could be integrated with advanced data dissemination techniques, as well as extension of analytics to farm management systems.

Lia Shrewsbury (c/o dhuggins@wsu.edu) WSU
Master's student, advised by Dave Huggins
Spatiotemporal variation of denitrification drivers

I identified the environmental and biological drivers of denitrification at different topographical positions and seasons within an agricultural field. I took soil environmental measurements and used them as possible explanatory variables. The predictive power of both possible and potential denitrification models was improved when spatiotemporal variation was considered, and it was improved further when nitrite reductase gene (nirK) abundance was considered. Modeling spatiotemporal variation is needed to predict denitrification rates and thus more accurately predict soil nitrous oxide emissions.

Alan Smith (smit6736@vandals.uidaho.edu) UI
Master's student, advised by John Abatzoglou
Microclimates in the inland Pacific Northwest

I am examining microclimatology using data collected from meteorology sensors on Moscow Mountain in ID to analyze the effects of microscale topographic influences. In addition, a new micrometeorology sensor will be deployed will be deployed at the Cook Agronomy Farm north of Pullman to analyze microclimatology in minor hilly terrain.



Stephen Taylor (stephen.e.taylor@wsu.edu) WSU
Master's student, advised by Dave Huggins
Developing decision support systems for farmers using precision nitrogen management technologies

My research is focused on developing science-based decision support systems for farmers using precision nitrogen management technologies in wheat. I will use variable-rate technologies, as well as differing prescription mapping technologies, to strengthen the way farmers make site-specific management decisions. General goals are to improve farming economics by lowering fertilizer inputs and maintaining yields, as well as decreasing the environmental impacts of chemical fertilizers.

Rachel Unger (rachel.unger@wsu.edu) WSU
PhD candidate, advised by Dave Huggins
Field-scale cropping system nitrogen use efficiency after 10 years of continuous no-tillage

Evaluating nitrogen use efficiency (NUE) for a longer time period that represents the cropping system may provide an improved assessment of NUE. In addition, cropping system NUE may vary spatially across heterogeneous landscapes and soils. Our overall objective was to use a niitrogen mass balance approach to better understand how terrain, no-tillage, and the implementation of multiple crop rotations influence cropping system NUE. Crop rotations initiated in the fall of 2000 and the spring of 2001 consisted of six different three-year rotations of spring wheat, winter wheat, and alternative crop (spring or winter plantings of barley, canola, lentils, or peas). We monitored all nitrogen inputs from fertilizer applications and nitrogen output from harvested grain at each of the georeferenced locations. Site-specific, field-scale assessments of NUE for each cropping system will be presented.

Sarah Waldo (sarah.waldo@email.wsu.edu) WSU
PhD candidate, advised by Brian Lamb
Measuring the emission and uptake of greenhouse gases over agricultural fields

Agricultural soils are an important source of nitrous oxide (N_2O), a greenhouse gas (GHG) with 300 times the warming potential of carbon dioxide (CO_2) per molecule. At the same time, agricultural fields can be a sink for CO_2 if the right management practices are employed. My research uses micrometeorological techniques (eddy covariance and flux gradient) to measure the exchange of these two GHGs over agricultural fields in the inland Pacific Northwest. The results will provide a baseline GHG budget for cropping systems in this area. The results will also be used to inform models such as CropSyst, which will improve larger-scale estimates of the GHG budget of agriculture in the region.

Chelsea Walsh (wals9279@vandals.uidaho.edu) UI
PhD candidate, advised by Jodi Johnson-Maynard
Earthworm distribution, activity, and effects on nitrogen cycling

Greenhouse experiments have shown that, under ideal soil conditions and high population densities, earthworms have the potential to increase crop yields by improving nutrient cycling, water infiltration, and soil structure. In reality, environmental thresholds limit the distribution of earthworms and the period of the growing season during which they remain active. This research aims to connect laboratory studies of earthworm thresholds and impacts to real world conditions, climate variation, and regional distribution by combining broad and focused approaches. This information will contribute to modeling the effect of earthworms on nitrogen cycling in the inland PNW.

Nicole Ward (ward5576@vandals.uidaho.edu) UI
Master's student, advised by Erin Brooks
Improving agricultural nitrogen management through policy incentivized practices

Precision agriculture, which focuses on applying variable inputs, including nitrogen, to match the field variability of crop needs, has been identified as a promising strategy to decrease the environmental harm due to excess nitrogen while maintaining high yields. Cost-share programs, created through Farm Bill legislation, are meant to provide incentives for the adoption of precision agriculture. This study will use an advanced cropping systems model, CropSyst-MicroBasin, to examine field-scale nitrogen management with an understanding of how economic policy incentives affect farm profitability and management practices by (1) assessing the impact of policy incentives on the profitability of adopting nutrient management practices, (2) quantifying changes in nitrogen export to the environment, and (3) evaluating how effectively the conservation policy incentives address nutrient management issues in the region.

Jenna Way (wayj@onid.orst.edu) OSU
Master's student, advised by Clark Seavert
Evaluating environmental and economic trade-offs in agriculture.

We are developing an environmental module, called AgEnvironment™, in AgTools™ for agricultural producers to measure environmental impacts at the farm level. AgTools™ is a decision-making tool for agricultural producers that analyzes the profitability and feasibility at the individual farm level of different cropping systems and management decisions. AgEnvironment™ will capture changes in climate and allow users to evaluate adjustments in yields, cropping systems, inputs, and environmental impact, providing the opportunity to evaluate environmental and economic trade-offs. Currently, we are researching tools to measure the impact of practices and inputs on the environment and farm-level sustainability, such as energy use, fertilizer and pesticide use, soil erosion, and greenhouse gas emissions.

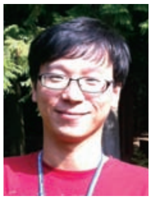
P. Troy White (pwhite@uidaho.edu) UI
PhD candidate, advised by Kattlyn Wolf
Inclusion of climate change in secondary education
My research focuses on the integration of climate science into the science and agriculture curriculum of secondary teachers in the PNW. Specific objectives include monitoring teacher perceptions relating to climate change and teaching of controversial science topics in their classes. The study uses both teacher workshops and REACCH-developed curriculum resources to train teachers on climate science and agriculture and then monitors their perceptions relating to climate change using a modified version of the Global Warming's Six Americas survey. In addition to the teachers' perceptions, we are collecting student content and attitudinal data to measure the impact of the curriculum and teaching resources on their knowledge and attitudes toward climate change and agriculture. This research improves climate literacy and examines teaching effectiveness.

Lauren Young (leyoung@wsu.edu) WSU
Master's student, advised by Frank Young
High-residue no-till using a stripper header to conserve soil moisture for planting of oilseeds
Growing winter triticale and a tall variety of winter wheat has increased residue production at the Ralston project by at least 35% when compared to crop years with semidwarf winter wheat. Using a stripper header for harvest leaves the crop residues standing, creating a different microclimate than when a conventional cutter bar header, which leaves shorter residue, has been used. The stripper header stubble results in decreased soil temperatures and decreased wind speeds at the soil surface, which contribute to soil moisture differences between stubble treatments. The stripper header no-till system conserves more moisture during the fallow year and can reduce the loss of soil to wind erosion.

Jialing Yu (yujia@onid.oregonstate.edu) OSU
PhD candidate, advised by Junjie Wu
Impact assessment of the federal crop insurance program
Agricultural production faces risks from various sources, such as weather conditions, pests, natural disasters, management errors, diseases, and price fluctuations. The federal crop insurance program has become a major risk management tool for the government. It is important to understand the effects of the program's policies and how changes in policy will affect these impacts.

Crop insurance is a voluntary program, which makes program participation a critical issue for the government in delivering the program and also for researchers in correctly assessing the program's impacts. The government has increased premium subsidies several times over the life of the program to encourage participation. Yet not all producers participate in the program. It is essential to understand the participation process, in that it selects the population that will be affected and therefore determines the distribution and magnitude of policy impacts. Farmers making participation decisions based on potential outcomes give rise to the selection problem in policy evaluation.

This study applies the Tradeoff Analysis Model for Multi-Dimensional Impact Assessment (TOA-MD) to the selection issue in the impact assessment and analyzes how policy changes may affect the program participation rate and thus the outcome impacts. TOA-MD is a population-based approach that links policy changes to participation and simulates distributional policy impacts, accounting for self-selection and counterfactual issues. It emphasizes the heterogeneity of the population, which affects the participation rate, and heterogeneous policy outcomes. The study focuses on regions with different characteristics and levels of heterogeneity, namely the Pacific Northwest, the Corn Belt, and the Great Plains, to understand the role that heterogeneity plays in program participation and impacts.



Hongliang Zhang (zhangh@onid.oregonstate.edu) OSU
PhD candidate, advised by John Antle
Climate change impacts on agricultural systems
My research focuses on assessing climate change impacts on agricultural systems and evaluating conservation tillage as a potential strategy for adapting to climate change . The study region is the East Cascades in the PNW, including the REACCH region. I use two different methodologies: statistical approaches and process-based approaches. I assess the vulnerability of agricultural systems under future climate scenarios based upon the estimated distribution of outcomes. Also, I investigate factors that drive the use of conservation tillage and evaluate the effects of conservation tillage on crop yields and production risk.

Xiaojuan Zheng (xiaojuanjudy@gmail.com) OSU
PhD candidate, advised by Jeff Reimer
Integrating representative agriculture pathways into the commutable general equilibrium model
My research study is trying to introduce representative agricultural pathways and scenarios (RAPS), which describe narratives and trends in key drivers at a regional or global scale, into a computable general equilibrium economic model. I estimate key economic relations econometrically using historical data, including a foreign export demand decision model and a PNW wheat output supply model. The general objective is to provide confidence intervals concerning economic variables of interest to development of the Pacific Northwest wheat sector over the next few decades.

REACCH students and team members gather for a discussion with Sonny Ramaswamy, USDA NIFA Director, at the University of Idaho, July 2014. Photo by Leigh Bernacchi.

Summer interns add fresh perspectives to REACCH research teams

Leigh Bernacchi (lbernacchi@uidaho.edu) UI, Kristy Borrelli UI, Jodi Johnson-Maynard UI, and Marijka Haverhals UI

REACCH provides the hands-on, real-life experience that undergraduate students need to become confident, knowledgeable, and impactful scientists. Since 2012, REACCH has trained a total of 41 undergraduate student interns. These students each spent a nine-week period doing independent research with REACCH faculty. In addition to research, students participated in seminars and workshops that targeted specific skills such as interdisciplinary collaboration, research and communication, and how to apply to and succeed in graduate school. As part of their experience, students were asked to write blogs to be shared with project participants and stakeholders. Here we highlight the experiences and work of the 2014 interns. Their full research blogs can be found on the REACCH website.

IMPACT

REACCH invests in training interdisciplinary scientists so that future generations can make informed decisions regarding climate and management and maintain resilient, sustainable, and profitable agricultural systems.

REACCH Undergraduate interns work at research sites all over the PNW including the OSU's Columbia Basin Agricultural Research Center. Photo by Rebecca Graham.

2014 interns take time for a final photo following their presentations describing their summer research experiences. Pictured: left to right back row: Zach Millang, Christian McGillen, Brita Olsen, Jacob Cohen, Rich Manuli; front row: Caitie Mack, Jenna Way, Savannah Sheehy, Rebecca Graham, Jashvina Devadoss, Carolyn McCotter, Allison Buiser. Photo by Marika Haverhals.

Cereal pests, like aphids pictured here, were the focus of several REACCH undergraduate intern projects. Over nine weeks, students develop the skills to produce scientific results for the project. Photo by Brad Stokes.

Allison May Buiser (Knox College), Kristy Borrelli UI, Chad Kruger WSU, and Georgine Yorgey WSU

Precision agriculture resources for farmers

We studied current precision agriculture (PA) technologies and practices in PNW wheat production through interviews and literature review. PA allows farmers to address the variability in nutrient availability and yields across fields. It may save farmers money and reduce environmental issues through the management of zones instead of uniform field management. We identified useful information about adopting PA practices through interviews with researchers and will make it available to farmers through extension materials.

Jacob Cohen (Pennsylvania State University), Ivan Milosavljevic WSU, and David Crowder WSU

Role of climate change in plant-insect interactions

Climate change projections for the PNW suggest that drought stress will increase for most crops in the next 50 to 100 years. Yet there is almost no information about how drought stress might interact with biological stressors to affect crop yields and quality. Our research addressed this knowledge gap by exploring interactions between drought stress, insect pests, and a viral plant pathogen. Specifically, we exposed plants to different combinations of virus (*Barley yellow dwarf virus*), insects (wireworms), and drought. This research is ongoing, but preliminary results suggest that feeding by wireworms significantly decreased plant quality and made plants more susceptible to other stressors. Our results suggest that biotic and abiotic stress may act additively to decrease plant yields. Future research should include such interactions to better understand how climate change will affect crop production.

Future climate scenarios could increase the likelihood that drought can impact wheat and associated organisms like insects and pathogens. Photo by Seth Davis.

Jashvina Devadoss (University of California, Berkeley), Erin Brooks UI, and Nicole Ward UI

Exploring field-scale variability with remote sensing and EMI sensors

To identify improvements in precision agriculture technology, I focused on two information technologies that address the definition of management zones and rates: remote sensing and electromagnetic induction (EMI) sensors. I looked at field variability, specifically at the relationship between changes in electrical conductivity and soil moisture, and the potential of bulk electrical conductivity to delineate management zones for precision agriculture. We generated preliminary results by comparing EMI data to soil properties, water content, topographic properties, Normalized Difference Red-Edge Index, and crop yield data. At this point, both the EMI and remote sensing maps must be used in conjunction with other tools to delineate precision agriculture management zones, and eventually producers will be able to map their own fields with these tools.

Rebecca Graham (Cal Poly San Luis Obispo), Stephen Machado OSU, Rajan Ghimire OSU, and Larry Pritchett OSU
Management effects on soil organic carbon pools

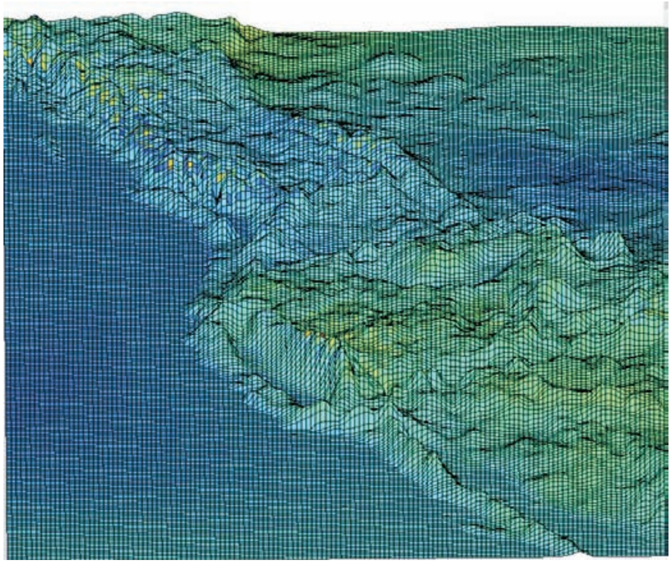
More than half of the stored soil organic carbon (SOC) has been lost in the last century due to soil disturbance. Understanding the factors that regulate SOC loss can help predict ecosystem responses to climate change. We measured potentially mineralizable carbon (PMC) in the winter wheat–summer fallow tillage fertility long-term plots at Columbia Basin Agricultural Research Center to determine how SOC and PMC contents change with tillage and soil fertility management practices. Results show that nitrogen application did not significantly affect SOC pools. With respect to tillage, plowing resulted in the lowest mineralizable carbon content. The PMC content under grass pasture was approximately 2.5 times more than PMC content under sweep tillage and about 8 times more than under plow tillage. This research indicates that reducing or eliminating tillage has the potential to increase SOC accumulation under dryland wheat-based cropping systems of eastern OR. More research will expand our understanding of how SOC pools respond to management and climate change.

Caitie Mack (Paul Smith's College), John Antle OSU, Susan Capalbo OSU, and Laurie Houston OSU
Strengths, weaknesses, opportunities, and threats analysis of California's Low Carbon Fuel Standard

The Low Carbon Fuel Standard is a "first-of-its-kind" regulation that has the ability to increase the use of renewable fuels. In order for this regulation to work properly, a cost containment strategy should be implemented. My internship with REACCH has led me to explore the history and future of renewable fuel standards and markets, with the hope of decreasing fossil fuel use. Price ceilings and floors will provide low-carbon fuel investors with a more precise projection of what the low price may be in the future, thus reducing the chance that they will lose money on their investment if prices suddenly drop dramatically. This will strengthen the incentives to invest in a low-carbon fuel.

Rich Manuli OSU, John Antle OSU, Susan Capalbo OSU, and Laurie Houston OSU
Obstacles in the oilseed biofuel market

Biofuels are a broad topic and have many variations in production and recycling resources. To get a better understanding of the oilseed market, I used AgProfit™ software to find the differences in the annual crop budgets of a model farm near Pendleton, OR, in a precipitation zone of 18 to 24 inches. I compared a winter wheat-pea rotation to one incorporating camelina. Selling camelina was not profitable without the tax credit, but when the producer processes the oil on site, it doubles the unit price (excluding the added cost of production). The evidence is clear that these oilseeds can be very profitable with the use of the tax incentives and the additional benefits of co-products, oilfuels, or an additional crop that helps wheat yields.



When global climate models are downscaled to regional climates, topography increases the validity of results. Image by Christian McGillen.

Carolyn McCotter (University of Puget Sound), advised by Sanford Eigenbrode UI, Seth Davis UI, and Nate Foote UI
Drought and cereal pests

One of the least studied factors of climate- and drought-altered conditions is the behavioral responses among insects. I conducted a study of the behavioral responses and interspecies relations of two aphid pests that infest Palouse cereal wheat under drought conditions. Results indicate that a strong within-plant competitive interaction is occurring between aphid species. This means that multiple aphid species, when on the same plant—which could become more common with climate-driven range expansion—may compete by inhibiting reproduction of conspecifics. However, population increases in general would impose a risk of diminished agricultural production.

Zach Millang (Virginia Tech), Phil Mote OSU, and Sihan Li OSU
Analyzing regional climate models for the Pacific Northwest

The global climate model (GCM) is the most sophisticated tool we have to better our understanding of how our climate will change. GCMs are made up of three-dimensional grid cells that take into account the physical conditions of our atmosphere, ocean, sea surface, and sea ice at a given time, but lack accurate representation of topography. We use dynamic downscaling to incorporate regional topography and create regional climate models (RCMs). The development of finer resolutions would offer relevant future climate scenarios. Farmers have many options for dealing with the weather, but the precision of an RCM will help them really know which one to invest in for the future.

As Carolyn McCotter learned in her internship, aphid (pictured) and drought interact to decrease overall cereal crop productivity. Photo by Carolyn McCotter.

Brita Olson UI, Kate Painter UI

Trends in crop progress and condition

Idaho Crop Progress and Condition Reports are weekly publications from the U.S. Department of Agriculture National Agricultural Statistics Service. From the mid-1980s to the present, these reports have had a more or less standardized format, which includes quantitative survey data describing the progress and condition of wheat. We found that the condition index for both spring and winter wheat shows a strong relationship to total season precipitation (September through June) and spring precipitation (April through June). Climate projections suggest that the PNW will see decreased summer precipitation. Depending on the timing of precipitation, this decrease could negatively affect the condition of our wheat crops.

Savannah Sheehy UI, Jodi Johnson-Maynard UI, and Ian Burke WSU

Earthworm impacts on soil weed seeds

In addition to improving soil physical properties and nitrogen availability, earthworms may also ingest and digest plant seeds. Seed predation may play a role in the development of the plant community, particularly with regard to the structure of the seed bank. We incubated replicate mesocosms with soil, earthworms (either deep or shallow burrowing), and weed seeds (prickly lettuce or field bindweed). Approximately 67% of prickly lettuce and 70% of field bindweed seeds were not recovered when incubated with the deep-burrowing earthworm species. These “missing” seeds were assumed to be destroyed in the digestive process. These findings suggest that practices favoring the presence of deep-burrowing earthworm species may result in a reduction in prickly lettuce and field bindweed seeds and germination.

Jenna Way OSU, Zach Millang (Virginia Tech), Susan Capalbo OSU, and Clark Seavert OSU

Integrating environmental accounting into AgTools

The AgTools™ software uses a suite of programs to evaluate the profitability and feasibility at the individual farm level of different management decisions and cropping systems. To properly integrate environmental effects of agriculture on climate change and farm-level sustainability, we researched the most significant variables: energy use, pesticide and fertilizer use, soil erosion, water use, and greenhouse gas emissions. We used AgEnvironment™ to evaluate case study farms under climate change conditions with different crop rotations. The more diverse cropping systems have the greatest economic success (in cash flow, net farm income, and cumulative net farm income). This shows that climate change has advantages to farmers, and if they are aware of these advantages, they can plan crop rotations accordingly. As far as policy implications for climate change, AgEnvironment™ has the potential to be used as a tool that analyzes economic impacts for farmers when they adapt to meet proposed climate change regulations

Savannah Sheehy monitors mesocosms in the greenhouse as part of her study on earthworms and weed seeds. Photo by Jodi Johnson-Maynard.

Developing mobile applications for agricultural decision management support

Stephen Fricke (sfricke@uidaho.edu) UI, Erich Seamon UI, Paul Gessler UI, and Brad Stokes UI

With mobile devices becoming the predominant method of Internet access, location-based applications are now being used to assist farmers in making important decisions that could affect the yield and quality of their crop. The REACCH cyberinfrastructure team has developed a set of tools that growers will be able to access on mobile devices out in the field, providing them with information that will help them make informed decision on how they can best protect their crops against pests.

IMPACT

A changing climate could have a significant impact on appropriate weed and pest management decisions in the Pacific Northwest. Mobile applications offer growers the ability to use decision support tools directly in their fields to make informed choices relating to their agricultural practices.

Using our developed ArcGIS Server/javascript/python model), we developed a mobile responsive base interface to enable the integration and analysis of REACCH datasets. Our initial foray into this area has focused on integrated pest management in combination with climatic weather parameters generated from 1979 to the present (Figure 1).

A REACCH application development team was created in 2014, consisting of members of the cyberinfrastructure, biotics, and extension teams. The groups worked to come up with a strategy to best serve growers' decision support needs, with the extension team working to determine the information growers would like to have and the biotics team working to provide phenological information about insects and plants. The cyberinfrastructure team developed a data process, in conjunction with the REACCH modeling team, to process weather parameters every three days to provide data for agricultural decision support analytics.

Crop growth and its relationship to weather parameters is an important component of the REACCH effort. As such, the calculation of growing degree days, which is a measurement of average heat accumulation used to predict plant and animal development rates, has been critical to the development of these decision support tools. We have created a REACCH growing degree day mobile application that displays a map of growing degree days for

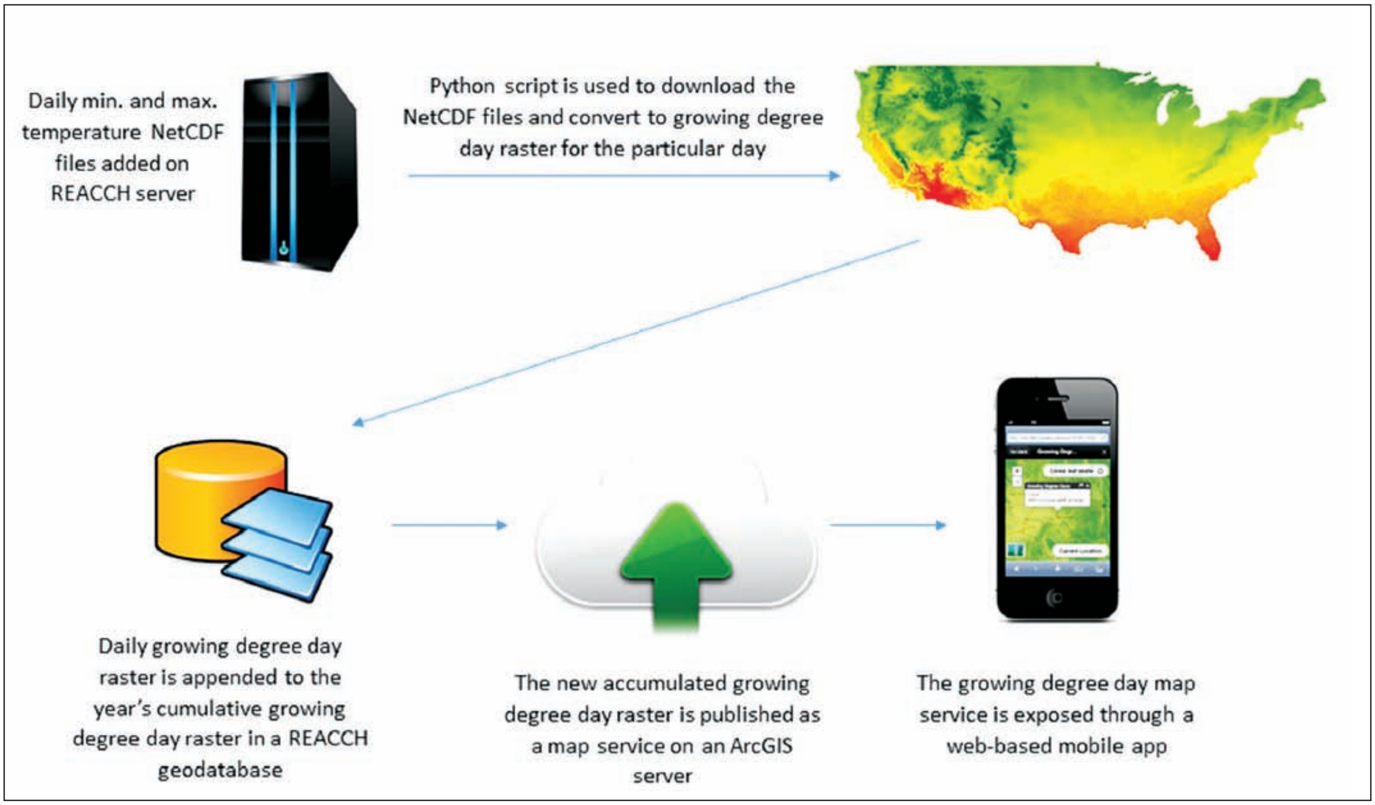


Figure 1. *The process of creating a real-time growing degree day mobile app.*

Figure 2. *Mobile app showing growing degree days for the cereal leaf beetle.*

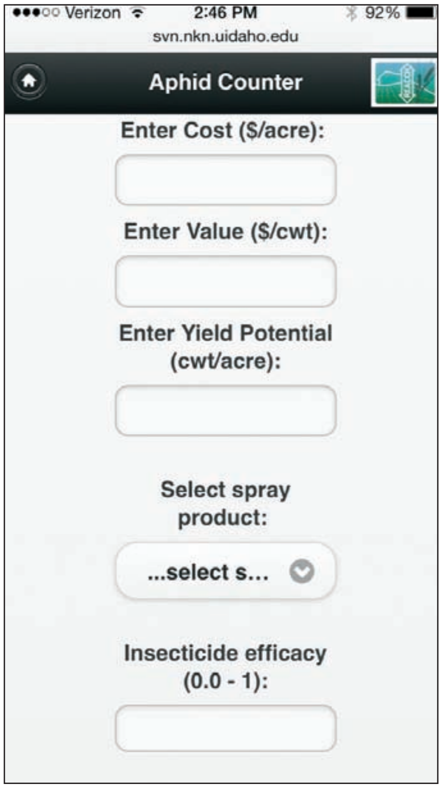


Figure 3. *Input screen for the parameters used in the Aphid Counter mobile app.*

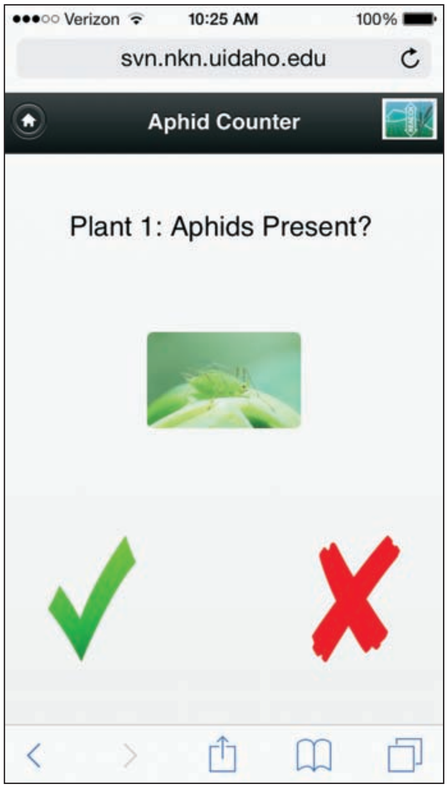


Figure 4. *Interface for the Aphid Counter mobile app.*

the entire contiguous United States, using REACCH scientist and University of Idaho associate professor John Abatzoglou's gridded meteorological datasets (Figure 2). The map is updated daily, displaying near-real-time growing degree day accumulations. The grower has the option to select the insect or plant of concern to them, and a gridded growing degree day layer will be overlaid on the map within the mobile application. They then have the option of clicking anywhere on the map to query how many growing degree days have accumulated at the selected area, as well as the corresponding phenology information for the insect or plant of interest. The grower can also simply select the Current Location button, and the GPS within the smartphone will determine the location of the grower and display the growing degree day accumulation and the associated plant or insect development stage information for that location.

Another mobile application that has been developed is a binomial sequential decision-planning application for managing pea aphids. The Palouse area of WA and ID accounts for a large percentage of the US production of dry peas. Infestations of pea aphids annually develop in nearly every dry pea field in the Palouse, which in turn reduces crop yield and quality. Variables including crop market value, cost of control, and crop yield potential are all important in determining the economic injury level to the dry pea plant or, in other words, the point at which it makes the most financial sense for a grower to spray for pea aphids. The developed mobile application allows the grower to input the cost of control, the market value of the crop, the crop yield potential, and the insecticide efficacy, which are then used to calculate the economic injury level for the crop (Figure 3). The grower is then taken to an interface where they are asked to start scouting their field, going plant by plant and tapping the check mark if the plant has any aphids present and the X if no aphids are present (Figure 4). Eventually, after a sufficient number of plants have been scouted, the tool will make a determination, based on the economic injury level of the plants and the abundance of aphids, as to whether it is economically advisable for the grower to spray an insecticide or not.

We are also currently working to make the University of Idaho's aphid tracker calculators mobile enabled. The calculators provide information such as which insecticide to use based on location, seed treatment cost, seeding rate, crop yield potential, and crop market value. There are calculators for both peas and lentils, and there are also different calculators depending on whether it is the early or late part of the growing season.

The ultimate goal of the REACCH decision support tools is to provide a user-friendly interface that allows growers to make informed decisions based on data provided by REACCH project researchers . Because the tools can be accessed on mobile devices, growers can have a set of useful decision support tools right in their pockets out in the field. We have a great start with the mobile tools currently developed, and we will continue to create new tools and make enhancements to our existing tool set. As more data are collected, we will be able to allow growers to query a growing list of insects and plants. Also, we hope to receive more feedback from growers to determine what they like or dislike about the mobile tools, in the hope that we can provide them with a product that is easy for them to use and helps them to make critical decisions for improving their agricultural practices.

AgBiz Logic™: Farm decision tools for changing climates

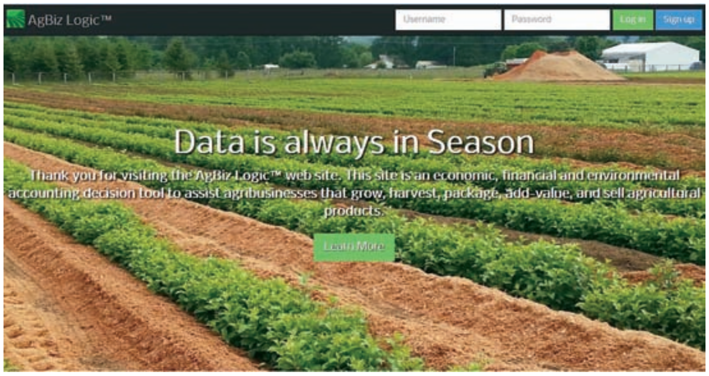
Clark Seavert (clark.seavert@oregonstate.edu) OSU, Susan Capalbo OSU, Laurie Houston OSU, and Jenna Way OSU

The REACCH project is committed to research and outreach designed to better inform stakeholders and society of the opportunities and challenges that a changing climate presents for agriculture in the Pacific Northwest (PNW). As such, REACCH researchers at OSU are developing a unique web-based decision support tool (AgBiz Logic™) for assessing the impacts of climate change in the PNW (Figures 1 and 2). AgBiz Logic™ will incorporate AgEnvironment™ into the suite of software programs in AgTools™ (AgProfit™, AgLease™, and AgFinance™), providing readily accessible tools, web-based modules, and information to farmers, ranchers, and land use managers so that they can better understand the financial and environmental trade-offs associated with alternative management decisions—all at a scale that is relevant to their operations. Farmers, through the use of this software, can compare the effects of changes in their specific farm-level economic costs and returns associated with alternative on-farm actions (changes in management, technologies, rotations, and crop choices) in response to changes in climate, policies, and prices. This is a powerful tool with the means to summarize climate information, to help farmers visualize and interpret the information that is available for their area, and, most importantly, to help them understand how this downscaled information could affect the costs and returns they are likely to face over the next 10 to 20 years. It is both a farm-level decision support tool and an assessment tool for researchers and government agencies to realistically determine how climate change and climate change policies may influence and affect regional agricultural sectors.

IMPACT

The goal of AgBiz Logic™ is to provide online web-based decision tools (AgTools™) that can empower farmers, growers, and land use managers to (1) use data unique to their specific farming operations to develop management pathways that best fit their operations under a changing climate, (2) understand how decisions about new programs, management options, and technologies/varieties may affect their net returns and livelihoods, and (3) better envision which actions farmers can take to build resilience to a changing climate.

By incorporating regional/downscaled climate change information, farm financial information, and on- and off-farm environmental impacts of management decisions into one suite of interconnected user-friendly programs, we can better connect growers and researchers. The downscaled information on climate influences projects yield changes over time. These yield changes are the impetus for producer-generated changes in input use, management, and technology adoption that may lessen negative impacts or take advantage of positive opportunities. The economic and financial calculators that are embedded into AgTools™ are the means for farmers to better understand how climate change may affect their lives and the environment they care deeply about. These types of decision tools are part of a global and national effort labeled "climate-smart agriculture" that focuses on making farms and farmers more resilient to a changing climate. They are the very heart of the recommendations made in the recent 2014 U.S. Government Accountability Office report 14-755, which speaks to the U.S. Department of Agriculture's ongoing efforts to better communicate information to growers.



Data is always in Season

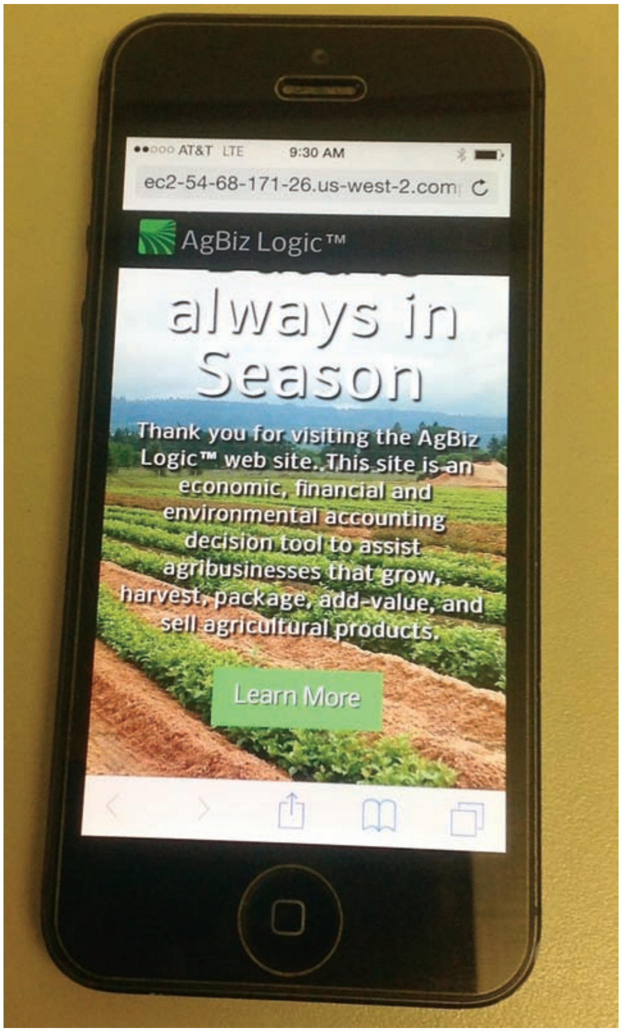
Thank you for visiting the AgBiz Logic™ web site. This site is an economic, financial and environmental accounting decision tool to assist agribusinesses that grow, harvest, package, add-value, and sell agricultural products.

Figure 2. *AgBiz Logic™ is a suite of software programs (AgProfit™, AgLease™, AgFinance™, and AgEnvironment™) used for capital investment analysis and environmental accounting.*

The use of AgTools™ in conjunction with AgEnvironment™ will also assist growers in the REACCH region and elsewhere to visualize and understand the range of changes (exposure to risk) to their net returns and to understand connections to both onsite and offsite environmental changes. This assessment tool provides the foundation of a truly integrated assessment and trade-off framework for assessing technology changes and changes in external drivers such as climate, water availability, and policy.

The overall objectives for this year are (1) to develop and pilot an online decision support tool for growers and researchers to assess the economic and financial impacts that changes in key factors (climate, water, and input costs) may imply for growers (stakeholders) in the REACCH region, and (2) to quantify the associated changes in key environmental dimensions that may affect production practices.

AgTools™ currently consists of a suite of software programs—AgProfit™, AgLease™, and AgFinance™—which contain return and cost information for crops and livestock. The new module, AgEnvironment™, is both an environmental accounting tool for farmers and a means to track and assess environmental impacts in a larger landscape. The program will allow a user to



Thank you for visiting the AgBiz Logic™ web site. This site is an economic, financial and environmental accounting decision tool to assist agribusinesses that grow, harvest, package, add-value, and sell agricultural products.

Figure 1. *AgBiz Logic™ will also be available as an iPhone app.*

store changes in environmental outcomes that will be incorporated with AgProfit™ and AgLease™ scenario files in a trade-off framework. An AgEnvironment™ scenario file could also be imported into AgFinance™ for a whole farm or ranch analysis of the economic, financial, and environmental impacts of a grower's decision. As modifications are made to annual cost and return budgets, the capacity to compare the environmental as well as economic and financial impacts of a grower's decision will be a powerful add-on. The goal of the interface of AgEnvironment™ with AgTools™ is to track the changes in key environmental measures resulting from a change in crop rotations, implementation of a new technology, use of a conservation practice, etc. that may be linked to projected climate changes.

AgEnvironment™ is meant to capture the key onsite and offsite environmental impacts using science-based environmental models and simulators. Onsite environmental measurements could include tracking uses and applications of insecticides, fungicides, miticides, herbicides, fertilizers, and other petroleum-based products. Offsite environmental impacts that could be tracked may include changes in soil erosion runoff or water quality. As it relates to climate change, AgEnvironment™ provides a defensible means to track carbon footprints, greenhouse gas emissions, and carbon sequestration. This would be useful information in support of future climate programs such as carbon policies and carbon trading markets.

The goal is to launch AgBiz Logic™—a new user-friendly online interface with AgTools™—by October 2015, as an assessment tool for REACCH-area growers that reflects and integrates the economic, financial, and environmental accounting of the AgProfit™, AgLease™, AgFinance™, and AgEnvironment™ programs. Prior to this milestone, we will work closely with the REACCH extension team to pilot the assessment tool with a subset of growers in the spring and summer of 2015.

Photo by Nita Robinson.

High-residue farming publications available for irrigated growers

Andrew McGuire (andrew.mcguire@wsu.edu) WSU Extension

Farmers in the irrigated regions of the Pacific Northwest (PNW) have not adopted high-residue farming to any great extent. High-residue farming (HRF) is an umbrella term that covers cropping systems in which the volume of the soil that is tilled is reduced in order to maintain crop residue cover of the soil. Crop residue covering the soil provides the many benefits of HRF, though the specific amount of residue will depend on the previous crop, the current crop, and soil and climate factors. No-till, strip-till, ridge-till, and vertical tillage are all variations of HRF. Many of these terms describe the type of tillage used (for instance, strip-till) or not used (no-till), and most also have other names, such as direct seeding for no-till, and zone tillage for shallow strip-till.

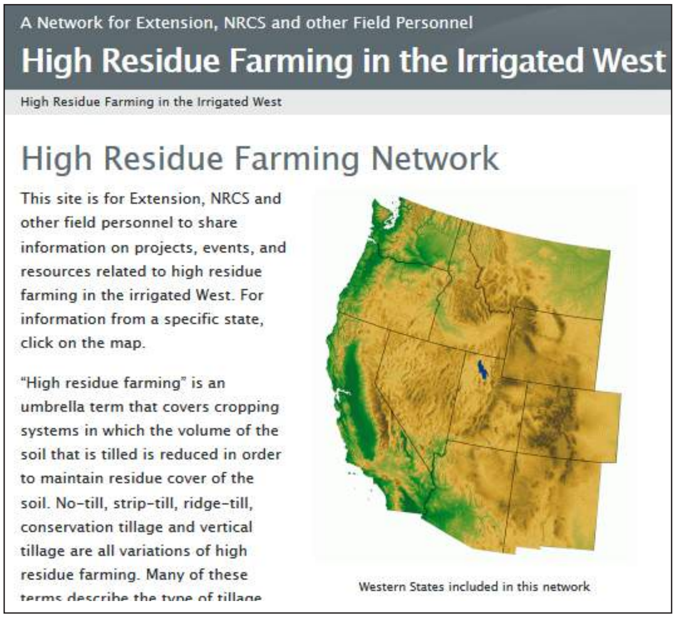
IMPACT

High-residue farming is relatively new to irrigated cropping systems of the PNW. A new series of extension publications will help irrigated growers to begin to adopt these systems more widely.

Compared to the Midwest, adoption of HRF in the PNW has been slowed by the challenges of using these systems with surface irrigation, by intensive crop rotations that include vegetables and other nonagronomic crops, and by the relatively less urgent soil conservation issues (at least in terms of precipitation-induced water erosion) in arid climates. Recently, however, needs for water conservation, a new interest in building soil quality, increased overhead irrigation, and increased focus on controlling wind erosion have spurred adoption of high-residue farming. To assist farmers with this major change, I have produced a series of extension publications:

These extension publications (Figures 2-6) will support producer decision making and adoption of high-residue farming practices in the irrigated region of the inland PNW. They were posted online in September 2014 and will be printed together in a booklet format (funded through the REACCH Extension Curriculum Grants Program) in October 2014.

The material in these publications is the basis of a four-hour workshop that I developed and conducted. In 2013, I held four of these workshops around the Columbia Basin of WA and one in Madras, OR. In post-workshop evaluations, 35% of participants rated the workshop as "outstanding," with another 54% rating it "above average." The number of participants is limited to facilitate good discussion and interaction. "The small group," commented one grower, "made it easy to learn." I am planning to conduct another three workshops during the winter of 2014-15, where I will also give out the printed booklets. The booklets were also available to growers at a December 2014 soils meeting in Moses Lake, WA, and will be provided at a February 2015 networked regional soil health workshop in the Columbia Basin.



A Network for Extension, NRCS and other Field Personnel

High Residue Farming in the Irrigated West

High Residue Farming in the Irrigated West

High Residue Farming Network

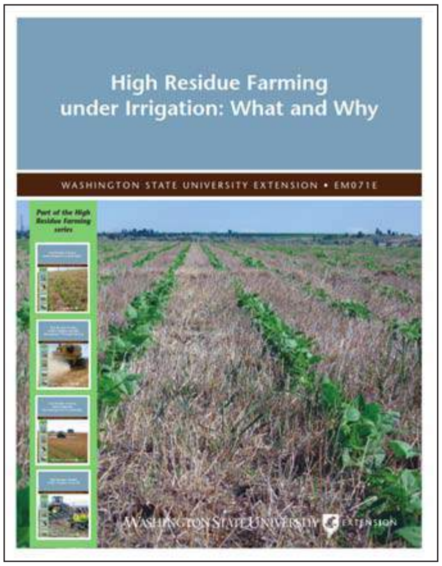
This site is for Extension, NRCS and other field personnel to share information on projects, events, and resources related to high residue farming in the irrigated West. For information from a specific state, click on the map.

"High residue farming" is an umbrella term that covers cropping systems in which the volume of the soil that is tilled is reduced in order to maintain residue cover of the soil. No-till, strip-till, ridge-till, conservation tillage and vertical tillage are all variations of high residue farming. Many of these terms describe the type of tillage

Western States included in this network

Figure 6. *High Residue Farming in the Irrigated West website.*

Although produced in WA, these publications are relevant to many regions of the irrigated West, especially those where overhead irrigation is common and high-value vegetables are grown. To reach out to this wider audience, a western regional network of extension, U.S. Department of Agriculture (USDA) Natural Resources Conservation Service, and other field personnel interested in high-residue farming was formed in early 2014 (funded by USDA Western Sustainable Agriculture Research and Education). A website set up for this network to share information, westernhrf.wsu.edu/, will be used to disseminate information about these HRF publications throughout the West (Figure 6).



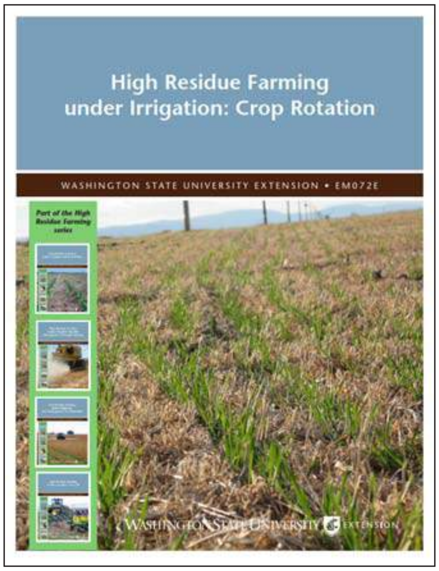
High Residue Farming
under Irrigation: What and Why

WASHINGTON STATE UNIVERSITY EXTENSION • EM071E

Part of the High Residue Farming series

WASHINGTON STATE UNIVERSITY EXTENSION

Figure 1. EM071 High Residue Farming under Irrigation: What and Why *provides an overview of high-residue farming, including its benefits and challenges. It also discusses some special considerations for high-residue farming in the irrigated agriculture regions of the far western United States.*



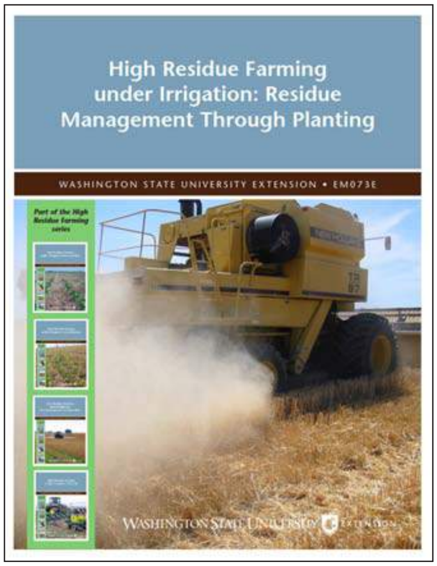
High Residue Farming
under Irrigation: Crop Rotation

WASHINGTON STATE UNIVERSITY EXTENSION • EM072E

Part of the High Residue Farming series

WASHINGTON STATE UNIVERSITY EXTENSION

Figure 2. EM072 High Residue Farming under Irrigation: Crop Rotation *covers choosing a cropping sequence, specific cover crops, and special considerations for irrigated cropping systems in the far western United States.*



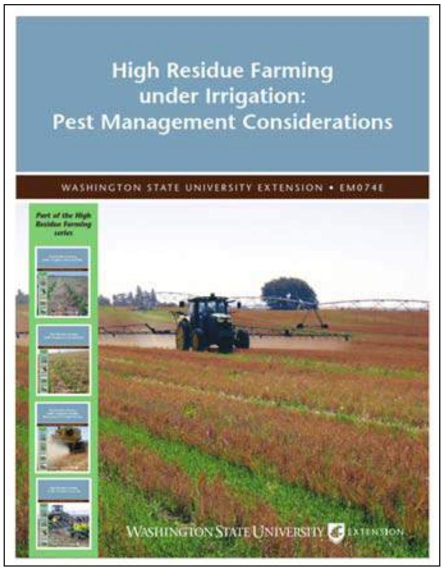
High Residue Farming
under Irrigation: Residue
Management Through Planting

WASHINGTON STATE UNIVERSITY EXTENSION • EM073E

Part of the High Residue Farming series

WASHINGTON STATE UNIVERSITY EXTENSION

Figure 3. EM073 High Residue Farming under Irrigation: Residue Management Through Planting *explains how to plant crops into high-residue conditions with a planter or drill. It covers residue management, planter and drill modification, and soil fertility adjustments.*



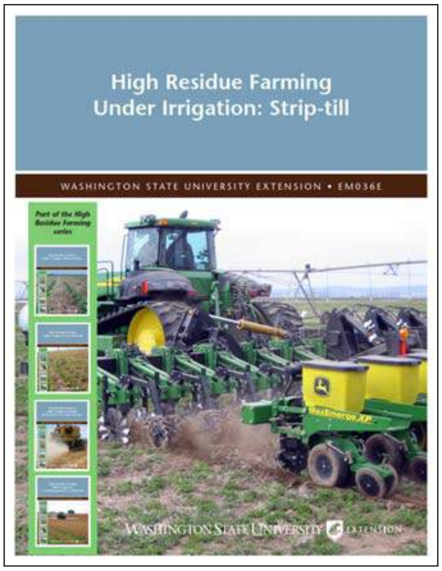
High Residue Farming
under Irrigation:
Pest Management Considerations

WASHINGTON STATE UNIVERSITY EXTENSION • EM074E

Part of the High Residue Farming series

WASHINGTON STATE UNIVERSITY EXTENSION

Figure 4. EM074 High Residue Farming under Irrigation: Pest Management Considerations *gives an overview of the effects of adopting HRF on the management of weeds, insects, and diseases.*



High Residue Farming
Under Irrigation: Strip-till

WASHINGTON STATE UNIVERSITY EXTENSION • EM036E

Part of the High Residue Farming series

WASHINGTON STATE UNIVERSITY EXTENSION

Figure 5. EM036 High Residue Farming under Irrigation: Strip-till *covers the benefits, challenges, and implementation of strip-till planting. This particular high-residue farming system combines some of the benefits of clean tillage systems with those of high-residue cover.*

Using time-lapse imagery for applied agricultural monitoring

Jyoti Jennewein (jjennewein@uidaho.edu) UI, Troy Magney UI, Caley Gasch WSU, Jan Eitel UI, and Lee Vierling UI

Remote sensing technology is advancing our ability to understand and monitor agroecosystems, particularly interactions among factors such as water availability, stress, nutrient availability, and crop production. However, these technologies are expensive and require technical know-how and interpretation skills. Yet the information gained from monitoring systems based on remote sensing is invaluable for determining long-term trends in agricultural landscapes.

IMPACT

Time-lapse imagery, captured using affordable time-lapse digital cameras, may prove useful in tracking the rate of crop senescence, both temporally and spatially, potentially providing insight into the drivers of crop productivity—and ultimately advancing our ability to monitor agroecosystems for improved agricultural decision making.

In recent years, there has been a growing movement to make remote sensing technology more accessible to people outside of the discipline. Our group, the Geospatial Laboratory for Environmental Dynamics at the University of Idaho, has been experimenting with the use of low-cost (~$150), weatherproof time-lapse digital cameras as an affordable, easy-to-use tool for monitoring spring wheat (*Triticum aestivum* L.) in the Palouse. With this in mind, the goal of this study was to investigate a method to monitor spring wheat throughout the growing season, using simple, affordable time-lapse digital camera technology.

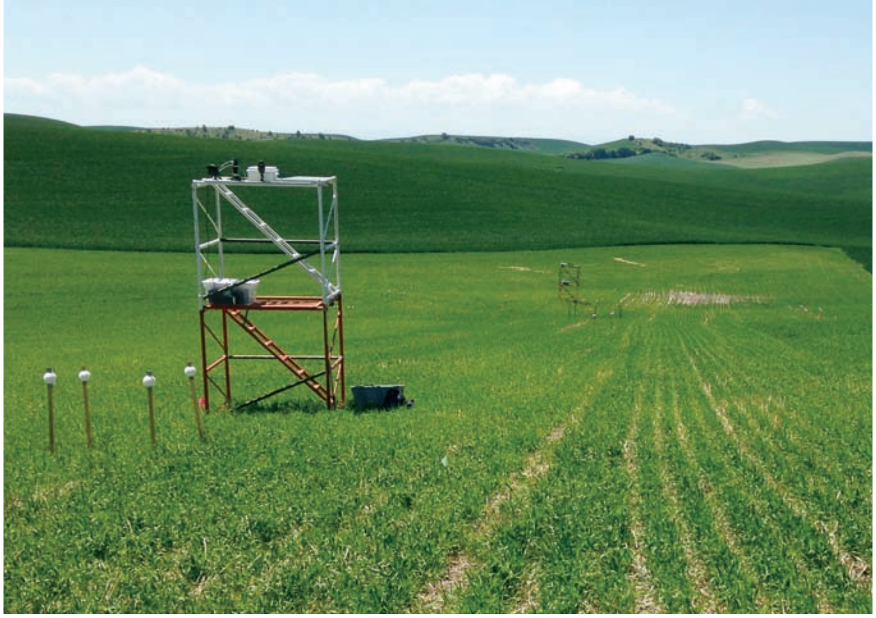


Figure 1. *Tower setup at the Washington State University Cook Agronomy Farm. Photo by Jyoti Jennewein.*

For the past two summers (2013 and 2014), four to six time-lapse digital cameras were mounted on three 15-foot-tall towers at the Washington State University Cook Agronomy Farm near Pullman, WA (Figure 1). Each camera was programmed to take between five and seven photos per day to monitor experimental plots under different nitrogen treatments (Figure 2). In the early summer of 2014, three different experimental areas were set up, each with sixteen 32-foot by 32-foot plots. Each plot received one of four nitrogen fertilizer treatments at planting: zero (0 pounds per acre), low (35 pounds per acre), medium (70 pounds per acre), and high (110 pounds per acre). Throughout the growing season, ground measurements of plant biomass, crop height, chlorophyll content (measured with a chlorophyll meter), and soil moisture were collected. These measures served as ground validation of crop development throughout the growing season, which were then compared to the values recorded in the red, green, and blue (RGB) band by the time-lapse digital cameras.

Every pixel from a digital image has an associated digital number (DN), which ranges from 0 to 255. The RGB visual data were analyzed using ImageJ, which allows the RGB DN values to be extracted from the digital images. DNs are related to the brightness, the amount of light energy, being reflected in each wavelength (red, green, and blue). Using the DN values in each image, we computed the relative percentage of brightness to account for day-to-day variations in weather, which alters the DNs associated with each pixel.

Three different vegetation indices (VI) were calculated from the DNs (Figure 3) and compared to our ground measurements through simple, bivariate correlations. These VIs include the green index, the green/red ratio, and the blue index, where the green and blue indices are simply ratios of brightness in one part of the spectrum normalized by cumulative reflectance in all three wavebands. For example, when calculating the green index, we took the DN for the green band and divided it by the sum of all three bands to normalize data from each plot for each sampling day. This allowed us to correct for changing illumination conditions (cloudy, sunny, etc.) as well as any differences that might be present between digital camera images.

Our results indicate that chlorophyll content correlates strongly with the green VI ($R^2 = 0.65$) on fields with higher soil moisture, and moderately well ($R^2 = 0.38$) on fields with lower soil moisture. However, none of the calculated VIs showed statistically significant relationships with the leaf area index, which is a measure of

Figure 2. *Time-lapse digital camera (on the right) mounted to monitor spring wheat throughout the growing season. Photo by Jyoti Jennewein.*

plant structure and is often related to plant biomass. This result suggests that digital imagery is more successful at remotely monitoring plant function (such as chlorophyll content) than plant structure. It also indicates that a visual examination of the chlorophyll content over different fertilizer concentrations is possible. Figures 4 and 5 display this detectable differentiation over time between fertilizer treatments in both chlorophyll measures (SPAD) and the green VI.

These results suggest that we can successfully monitor the distribution of soil water content using time-lapse digital cameras, since crops that have less water available start to senesce and lose chlorophyll earlier in the growing season. The summary of the results in Figure 3 demonstrates that there is a detectable, statistically significant ($p < 0.05$) relationship between soil water content and the three VIs calculated from the digital images. These trends are especially visible once peak greenness in spring wheat is reached and dry-down begins.

Figures 4 and 5 demonstrate the time-series similarities in chlorophyll content (SPAD) and the green VI, starting at peak greenness and continuing through the dry-down period. This correlation is important because field locations that exhibit early-season crop senescence may be candidate areas for adjusting seeding density, fallow, or crop types so that limited soil water is used efficiently. Furthermore, preliminary analyses of these data reveal that it may be possible to detect a relationship between the VIs and crop yield at the end of a season. However, additional analyses are needed to determine the reliability and feasibility of such methodology.

The results from this study help advance the case for using time-lapse digital imagery in future scenarios involving the timing and spatial distribution of senescence (dry-down) in crops throughout the growing season. They suggest that we can track the rate of crop senescence both temporally and spatially, potentially providing insight into the drivers of crop productivity—and ultimately advancing our ability to monitor agroecosystems for improved agricultural decision making.

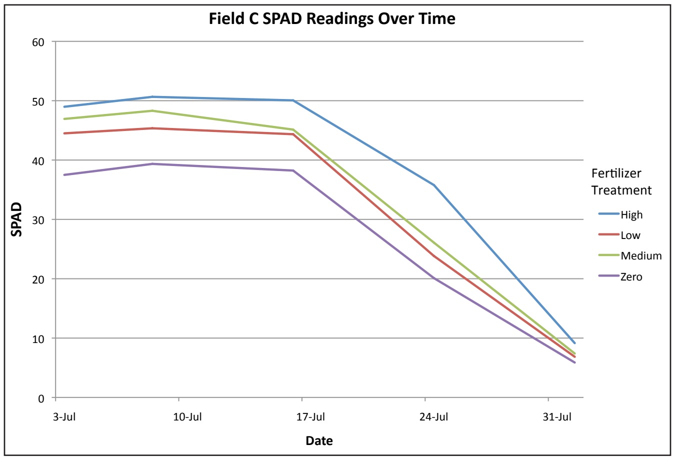


Figure 4. *Chlorophyll content (as measured by SPAD readings) starting at peak greenness and continuing through the dry-down period.*

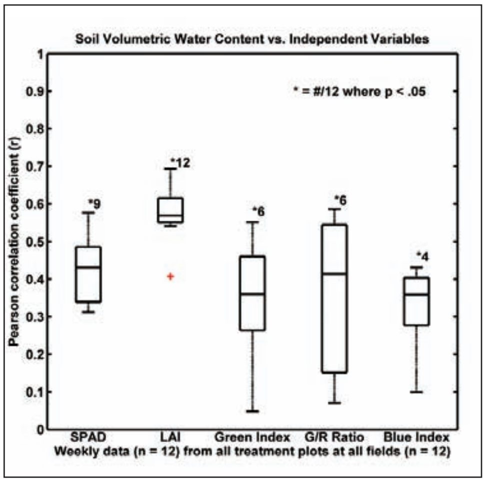


Figure 3. *Correlation of three vegetation indices (green index, green/ red ratio, and blue index), chlorophyll content (SPAD readings), and leaf area index (LAI) with soil volumetric water concentrations.*

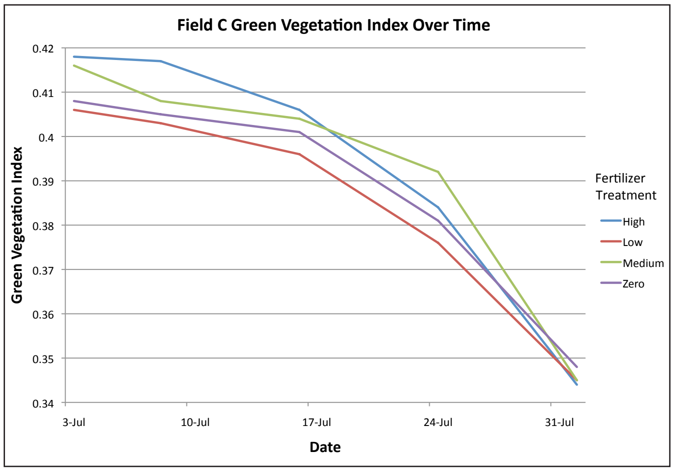


Figure 5. *The calculated green index starting at peak greenness and continuing through the dry-down period.*

Asymmetric warming projections for the inland Pacific Northwest

John Abatzoglou (jabatzoglou@uidaho.edu) UI, David Rupp OSU, and Philip Mote OSU

Increased temperature is a fundamental response to increased concentrations of atmospheric greenhouse gases. However, the way in which warming is manifesting may vary substantially geographically, across seasons and even from night to day. Observed warming over the last century has not been uniform; rather, high-latitude land masses have warmed at a faster rate than oceans or lower-latitude land masses. Across western North America, the increase in spring temperatures since 1950 has substantially exceeded the increase in autumn temperatures. And finally, while the annual mean temperature over the northwestern United States has warmed by 1.3°F since 1900, the coldest night each winter has warmed at nearly three times that rate.

IMPACT

The rate of projected warming for the warmest and coolest days may vary, resulting in additional opportunities and stressors for agriculture in the inland PNW. Whereas the mean increase in temperature projected for the region by the latter half of the 21st century is around 9°F, the rate of warming is projected to be far more acute for the coldest days of the year and slightly higher for the hottest days of the year. Collectively, this would result in significant changes in cold hardiness zones across the region that may allow for more cold-intolerant perennial crops not currently suited to cultivation in the region.

Climate projections often focus on the amount of warming in mean annual temperature for a geographic region. However, given the ways in which temperature changes have occurred, identifying robust aspects of projected temperature change may help better focus adaptation efforts. For example, will climate change lead to a uniform amount of warming throughout the year in both daytime high and overnight low temperatures? Will the hottest days of the summer warm disproportionately more than an ordinary summer day? Will overnight low temperatures in winter warm more than daytime highs in winter?

To answer these questions, REACCH scientists combed through daily maximum and minimum temperatures from 20 global climate models (GCMs) run for historical (1950 to 2005) and future (2006 to 2099) experiments. They examined differences in rates of seasonal warming, as well as changes in maximum (T_{max}) and minimum temperature (T_{min}) during both winter (December through January) and summer (June through August) from the last half of the 20th century to the last half of the 21st century. Because warming rates may vary geographically, they focused on regional-averaged rates of temperature change covering the inland Pacific Northwest (PNW) (42° to 49°N, 111° to 121°W), consisting of the entire REACCH region, including all of Idaho and western Montana.

Projected changes in temperature across the inland PNW by the latter half of the 21st century depict an average warming of 9°F (5.5° to 11.5°F), assuming a continuation of greenhouse gas emissions. However, this warming of 9°F is not uniform in time and space. Seasonally, temperatures are projected to warm slightly more during the summer (10°F) than in the other seasons (Figure 1a). Also, additional modeling experiments by REACCH scientists using regional climate models that are capable of resolving the Cascades and Northern Rockies reveal amplified warming during the spring at higher elevations due to the recession of snow cover.

All models project amplified warming rates for overnight low temperatures compared to daytime high temperatures during the winter months, with minimum temperatures warming nearly 2°F more than maximum temperatures (Figure 1b). Enhanced warming of winter overnight temperatures may curtail cold damage for agricultural systems, although cold damage may paradoxically increase in the absence of snow cover. Conversely, nearly all models project daytime high temperatures to warm faster than overnight low temperatures in the summer months. The additional warming of daytime high temperatures coincides with general declines in summer precipitation, relative humidity, and cloud cover. These changes collectively result in increased potential evapotranspiration and moisture stress for irrigated agriculture as well as native ecosystems.

Impacts often result from exceptional meteorological events, and the severity and frequency of these events may change as the climate changes. Temperature extremes have notable impacts on human health, ecosystem function, and energy demand. The models project amplified rates of warming for the coldest winter minimum temperatures compared to the average warming in daily minimum temperatures during winter. While there is a broad range of projections across the different models, the coldest winter night that one might experience per decade (strictly defined as having a 0.1% chance of occurring during any winter day) warms by 16°F in the multimodel average, nearly twice the rate of warming projected for the warmest winter night one might experience in a decade (Figure 2a). Likewise, the models project an amplified warming rate of the warmest summer daytime temperatures relative to the average increase in daily maximum temperatures in summer, whereas the coolest daytime high temperatures in summer will warm at a slower rate (Figure 2b). The researchers hypothesize that these asymmetric changes will arise due to a combination of thermodynamic and land-surface feedback factors. For example, heightened warming rates for the

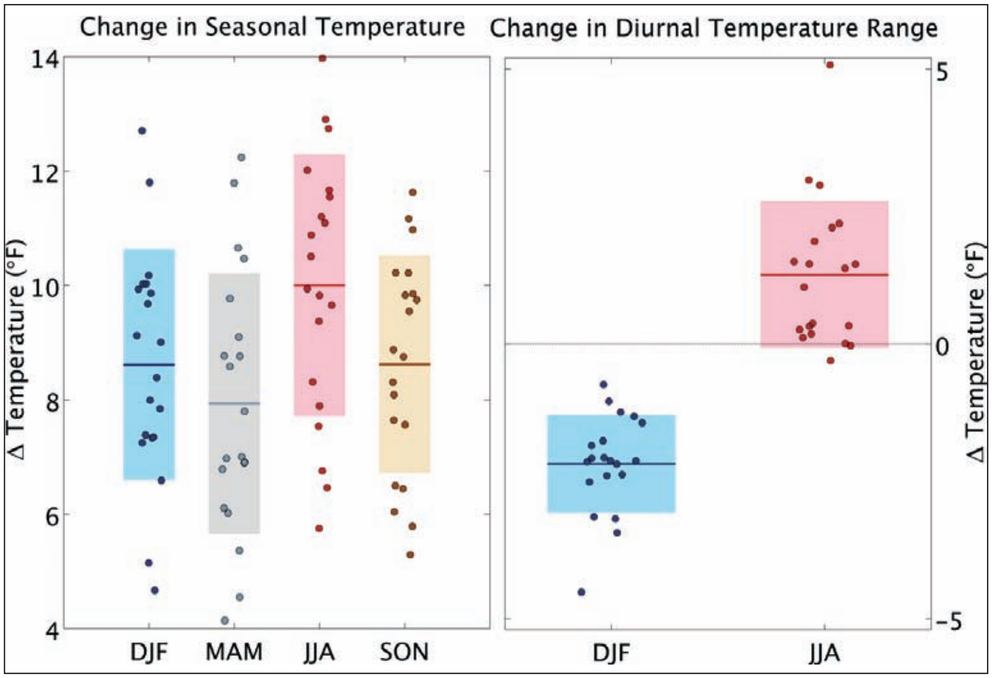
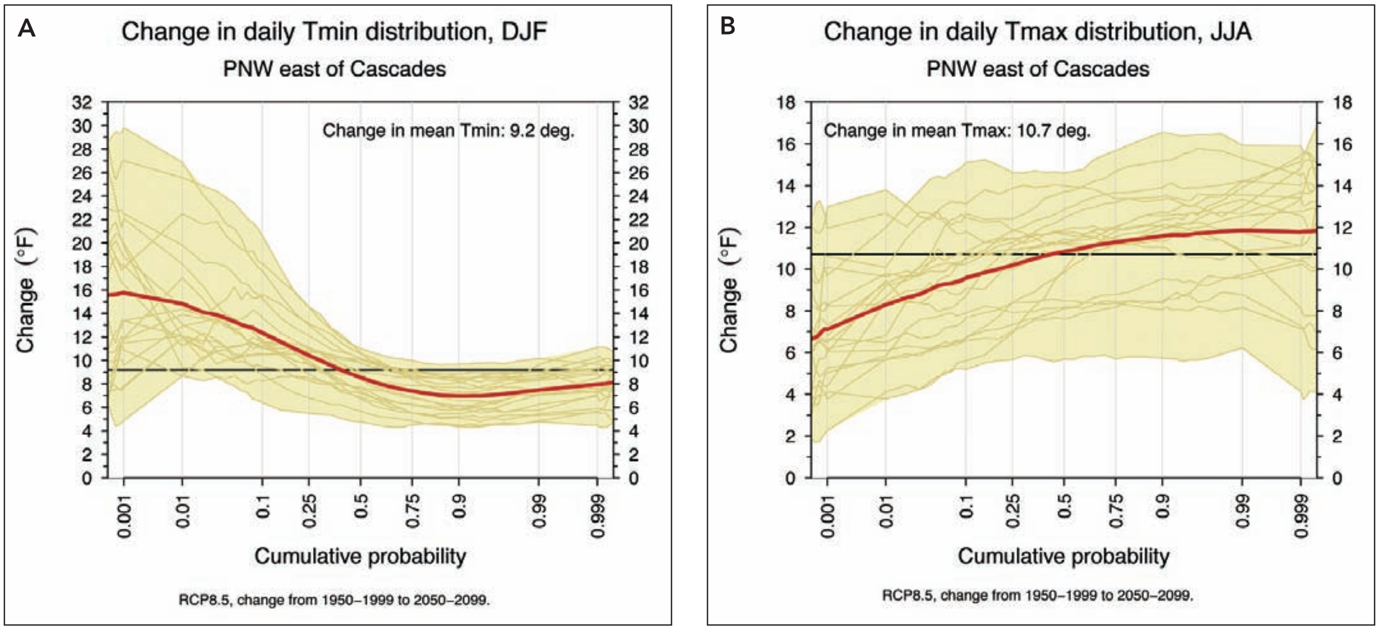


Figure 1. *Differences in temperature between 2050 to 2099 and 1950 to 1999, averaged over the inland PNW (42° to 49°N, 111° to 121°W) for 20 global climate models run using representative concentration pathway (RCP) 8.5. (a) Mean temperature changes for winter (December through February), spring (March through May), summer (June through August), and autumn (September through November). (b) Change in diurnal temperature range (daily high temperature minus daily low temperature). The results for each model are denoted by a dot, the horizontal line shows the 20-model mean, and shading denotes values within one standard deviation from the mean.*

coldest winter nights are a likely consequence of amplified warming over interior Canada, which serves as a source region for outbreaks of cold air, whereas amplified warming for the warmest summer days may arise due to a reduction in summer soil moisture, which allows more energy to be used to heat the land surface rather than to evaporate water.

These changes have implications for adaptation to climate change that might otherwise be neglected by assuming a constant warming rate. For example, the significant warming of the coldest nights of winter may result in dramatic changes in both agricultural crops and pests that can successfully overwinter in the region. These changes may also allow for the establishment of agricultural systems novel to the inland PNW that may otherwise be considered unviable under uniform warming. Additional warming of peak summer temperatures will likely have implications for peak energy demand and pose risk to systems that are not thermally adaptive. Collectively, the asymmetric warming projected by the GCMs presents both challenges and potential opportunities for agriculture in the inland PNW.

Figure 2. *Cumulative probability of differences in (a) winter daily minimum temperature and (b) summer daily maximum temperature between 2050 to 2099 and 1950 to 1999, averaged over the inland Pacific Northwest (42° to 49°N, 111° to 121°W). Results for individual models are shown by light lines, while the bold red line shows the 20-model average. For reference, the dashed horizontal line shows the 20-model mean change.*



Representative agricultural pathways and scenarios for integrated assessment

John Antle (john.antle@oregonstate.edu) OSU, Jianhong Mu OSU, Hongliang Zhang OSU, Susan Capalbo OSU , Sanford Eigenbrode UI, Chad Kruger WSU, Claudio Stockle WSU, J. D. Wulfhorst UI, and John Abatzoglou UI

Representative agricultural pathways and scenarios (RAPS) are projections of plausible future biophysical and socioeconomic conditions used to carry out climate impact assessments for agriculture. The development of RAPS is motivated by the fact that various global and regional models used to assess the impact of climate change on agriculture have been implemented with individualized scenarios using various data and model structures, often without transparent documentation or public availability. These practices have hampered attempts at model intercomparison and improvement, and at synthesis of model results across studies. For purposes of integrating impact assessments, therefore, the development of RAPS is important not only for building consistent sets of pathways and scenarios for intercomparison, but also for extending those scenarios to relevant future pathways and scenarios with a consistent set of drivers, both globally and regionally.

IMPACT

The development of representative agriculture pathways and scenarios (RAPS) can help scientists better characterize the range of uncertainty in climate change impacts and in adaptation and mitigation efforts. The framework of RAPS will also allow scientists to assess a wider range of individual studies by grouping them according to common assumptions they make about socioeconomic conditions or climate change outcomes.

The need for RAPS is demonstrated by recent research on climate impacts in agriculture. Preliminary research has shown that on average, farmers producing winter wheat could potentially obtain higher yields with future climates. However, the future world is uncertain in many dimensions, including commodity and input prices, production technology, and policies, as well as increased probability of disturbances (pests and diseases) associated with a changing climate. Existing models incorporate only a few of these factors, so we need a tool to represent and quantify these factors for modeling purpose.

To develop pathways and corresponding scenarios at regional or local scales, teams of scientists and other experts with knowledge of the agricultural systems and regions work together

Photo by Nita Robinson.

Table 1. *Likely trends of variables for REACCH representative agricultural pathways and scenarios (RAPS).*

Category	Variable/ indicator	RAP1 (business as usual)	RAP2 (dysfunctional world)	RAP3 (sustainable development)
Biophysical	Reduction in soil erosion	↗	↗	↗
	Irrigation	↘	↘	↗
	Pests, weeds, and diseases control	→	→	↗
Institutional/ policy	Commodity subsidies	↘	↘	↘
	Crop insurance subsidies	↗	↘	↘
	Conservation and environment programs	↗	↘	↗
Socioeconomic	Farm size: commercial	↗	↗	↗
	Gross domestic product (GDP)	↗	↗	↗
	Population	↗	↗	↗
	Adaptive capacity	XXX	XXX	XXX
Technology	Improvements in conservation technologies	↗	→	↗
	Pest management effectiveness	↗	→	↗

Continued next page

Table 1 (*continued*)

Category	Variable/ indicator	RAP1 (business as usual)	RAP2 (dysfunctional world)	RAP3 (sustainable development)
Prices from global/national models (without climate change)	Wheat	→	↘	↗
	Corn	→	↘	↗
	Cattle	→	↘	↗
	Chemicals	→	↗	↗
	Fertilizers	↗	↗	↗
Prices from global/national models (with climate change)	Wheat	↗	→	↗
	Corn	↗	→	↗
	Cattle	↗	→	↗
	Chemicals	↗	↗	↗
	Fertilizers	↗	↗	↗

through a stepwise process. In this process for the REACCH project, team members document the basis for the likely trends in key variables, and then use this information to develop model-specific quantitative scenarios. Using historical data, global economic model projections, and experts' opinions, we developed three RAPS for the REACCH region by midcentury:

Business as usual. In this scenario, rural development continues, with moderate increases in population in regional centers, larger and more diversified regional economies, and continued trends toward mechanical, chemical, and biological technology. Trends toward environmental regulation to protect air and water quality also continue, but fiscal pressures lead to real reductions in traditional commodity subsidies and other agriculture-specific conservation programs, making conservation more individualized. Agricultural prices increase in real terms due to continued growth in demand, especially for feed grains and for politically mandated production of biofuels. Some rural farm-based communities continue to sustain infrastructure and social cohesion, while others continue to experience net out-migration;

Dysfunctional world. In this scenario, unbalanced rural development occurs, with an almost complete loss of "agriculture in the middle" and consolidation of most commodity production into large corporate entities with contract arrangements for farm management and subsequent effects on rural farm-based communities. Suburban development continues largely unregulated in periurban areas as well as in more rural areas. Traditional farm subsidy programs are largely eliminated, conservation and environmental programs are limited due to budget constraints, and social conflict in agricultural communities escalates. Advances in large-scale mechanical, chemical, and biological technology continue, but disruptions to global agricultural research and development and agricultural trade result in substantially higher and more volatile agricultural commodity prices.

Sustainable development. Here rural development continues, with moderate increases in population in regional centers and larger and more diversified regional economies having a positive impact on community and social well-being. Traditional commodity subsidies are replaced by a carbon tax and an expansion of conservation and environmental programs, which slow the consolidation of land into larger farms and support some expansion of mid- and small-scale farms. Recent trends in mechanical, chemical, and biological technology continue, but in response to the carbon tax there is more innovation in technology that helps reduce fossil fuel intensity. Global commodity prices rise moderately along with the increases in fossil fuels due to the carbon tax.

Each RAP includes a set of variables to project plausible future biophysical, institutional/policy, socioeconomic, and technological conditions. As shown in Table 1, the team developed likely trends for each variable in each RAP. Table 2 quantifies these likely trends for modeling purposes, showing the possible range for each trend. This will enable other modeling teams to calibrate parameters to incorporate uncertainties from future world developments into their impact assessments. For an application that uses RAPS in the economic model, please refer to the companion article "Economic impacts of climate change on winter wheat" on page 110.

Table 2. *Possible range of variables for REACCH representative agricultural pathways and scenarios (RAPS).*

Category	Variable/indicator	RAP1 (business as usual)	RAP2 (dysfunctional world)	RAP3 (sustainable development)
Biophysical	Reduction in soil erosion	–10 to 0	–10 to 0	–10 to 0
	Irrigation	–5 to 0	–10 to –5	+10 to 20
	Control of pests,, weeds and diseases	–10 to +10	–10 to +10	20 to 40
Institutional/ policy	Commodity subsidies	–30 to –50	–80 to –50	–100 to –80
	Crop insurance subsidies	+50 to 100	–80 to –50	–100 to –80
	Conservation and environment programs	+20 to 40	–80 to –40	+50 to 100
Socioeconomic	GDP	+130 to 150	+50 to 80	+100 to 130
	Population	+20 to 40	+20 to 40	+20 to 40
	Farm size – commercial	+40 to 60	+60 to 80	+10 to 30
	Adaptive capacity	XXX	XXX	XXX
Technology	Improvements in conservation technologies	+20 to 40	No change	+60 to 100
	Pest management effectiveness	+20 to 40	No change	+60 to 100
Prices from global/ national models (without climate change)	Wheat	–30 to 0	–70 to –30	+0 to 30
	Corn	–30 to 0	–70 to –30	+0 to 30
	Cattle	–30 to 0	–70 to –30	+0 to 30
	Chemicals	+0 to 30	+30 to 60	+70 to 100
	Fertilizers	+0 to 30	+30 to 60	+70 to 100
Prices from global/ national models (with climate change)	Wheat	–20 to 50	–60 to 20	+10 to 80
	Corn	–20 to 50	–60 to 20	+10 to 80
	Cattle	–20 to 50	–60 to 20	+10 to 80
	Chemicals	+30 to 60	+60 to 90	+100 to 130
	Fertilizers	+30 to 60	+60 to 90	+100 to 130

Note: All changes are in percentages from the low to high end of the range. For scenario construction, all variables are simultaneously set to the low, middle, and high range (3 RAPS × 3 levels per RAPS = 9 scenarios). XXX = not used.

Economic impacts of climate change on winter wheat

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Updated climate projections from most recent global climate models have estimated climate change in the Pacific Northwest (PNW) by the middle of this century, with warming of 1.8° to 9°F (1° to 5°C), drier summers, and reduced spring peak flow. Preliminary research has shown that winter wheat yields in this region could increase with the combined effects of changes in climate and an increase in atmospheric carbon dioxide concentrations (see the companion article "Agricultural productivity under future climate scenarios" page 112). However, changes in farmers' profits from winter wheat production in the future will be determined not only by climate change, but also by other factors, including changes in commodity prices, production costs, production technology, farm policies, and the occurrence of pests and diseases. We have incorporated these other factors into an analysis of climate change impacts by constructing plausible future "pathways" using global economic model projections for prices and by using expert judgment for factors such as policy that cannot be modeled. Here we summarize some research results that project the economic impacts of climate change on the winter wheat production system in the REACCH region under three plausible projections of future conditions that we call representative agricultural pathways and scenarios, or RAPS.

IMPACT

Results of this study will help policy makers and governments create more target-oriented farm policies. Although even the average net impacts of climate change are beneficial in this region, there are still some losers due to variations in weather, biophysical, and socioeconomic conditions. In addition, information from this study could help in the development of improved climate change adaptation and mitigation strategies by presenting a range of uncertainties from climate model projections, emission scenarios, and future world development.

Figure 1 shows the research framework. This study uses downscaled climate data from multiple climate model projections for different emission scenarios (representative concentration pathways, or RCPs), simulated crop yields from a crop simulation model (CropSyst), economic data from the Census of Agriculture, and regional RAPS. Members of the REACCH team collaborated to develop three regional RAPS for conditions in midcentury (2050) based on historical data, global economic model projections, and experts' judgments (these RAPS are described in the companion article "Representative agricultural pathways and scenarios for integrated assessment" page 106). These regional RAPS were developed to be consistent with global pathways called shared socioeconomic pathways (SSPs), which are used along with climate change projections in an economic model called Tradeoff Analysis Minimum Data (TOA-MD) to simulate future economic, environmental, and social outcomes for the winter wheat-based farms in the REACCH area.

The TOA-MD economic model uses a statistical description of the winter wheat-producing farms in the REACCH region (based on agricultural census data) to assess the economic impacts of climate change. We used the TOA-MD model to analyze the average impacts on winter wheat-producing farms and the vulnerability of farms to economic losses. Figure 2 shows one of the key inputs to the TOA-

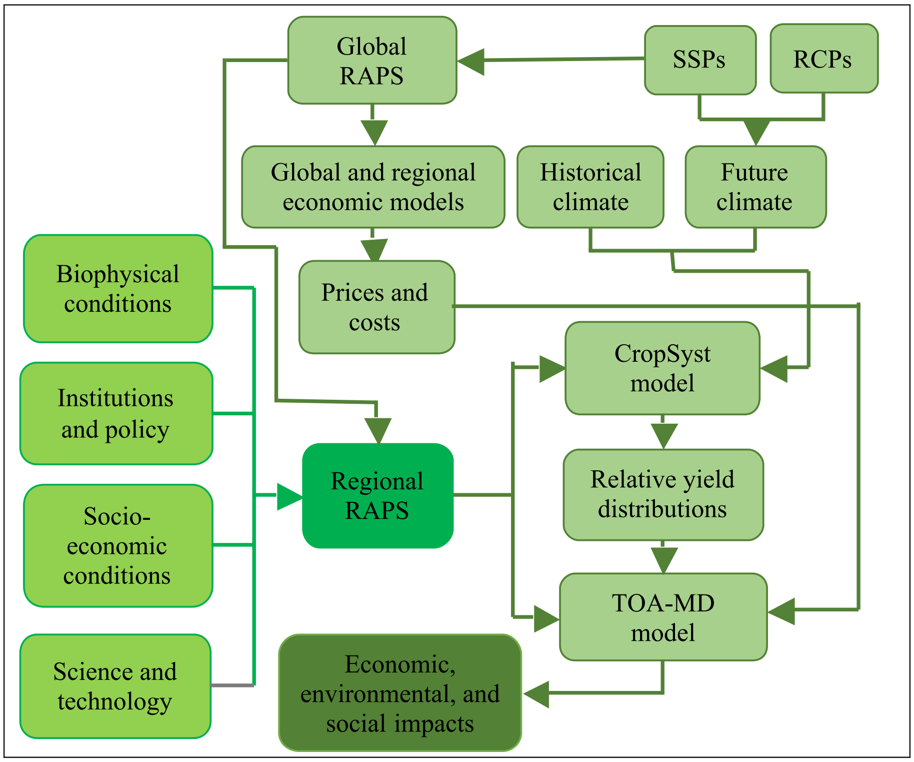

Figure 1. *An integrated regional impact assessment framework. (Note: RCP = representative concentration pathway, SSP = shared socioeconomic pathway, RAPS = representative agricultural pathways and scenarios, TOA-MD = economic impact assessment model.)*

MD model: the distributional changes in future winter wheat yields across global climate projection models for two emission scenarios by midcentury. This figure shows two important features: first, the impact on average yield is likely to be positive; however, because of the heterogeneity of the winter wheat production system across farms under future climate conditions, a substantial proportion of farms could still be vulnerable to losses from climate change.

Figure 3 answers the question of how the current winter wheat production system responds to climate change, summarizing outputs from the economic model. We find the results shown here across multiple climate projection models and two emission scenarios for midcentury (2050), although it is unlikely that current economic conditions will prevail in the future. The average net impact as a percentage of net farm returns ranges from 6% to 22% under the lower-emission scenario and from 3% to 24% under the higher-emission scenario, whereas 22% to 39% and 19% to 44% of farms are vulnerable to economic losses from climate change under the lower- and higher-emission scenarios, respectively. These results also suggest that a larger variation in climate change impacts is coming with projections of a warmer and drier climate.

To answer how the future winter wheat production system will respond to climate change, Figure 4 summarizes results from the TOA-MD model. As shown in the figure, the economic impacts differ substantially depending on the scenario used in the simulation. For each RAPS, four alternative conditions are simulated: a world with high commodity prices and high costs of production (HH), a world with high commodity prices and low costs of production (HL), a world with low commodity prices and high costs of production (LH), and a world with low commodity prices and low costs of production (LL). These results show that under the “business as usual” RAP1 and high prices, in which higher wheat prices are projected, wheat farmers would gain on average from 30% to 50% (in farm net returns), but about 20% of farms would be losers, with losses in the range of 15% to 25%. The most pessimistic scenario (RAP3, with low prices) shows average economic gains of 0% to 20%, with 22% to 55% of farms vulnerable to losses. We can conclude that there is a high degree of uncertainty associated with climate change, but it is clear that the overall impact as well as the degree of vulnerability will depend substantially on future economic conditions as well as on climate change.

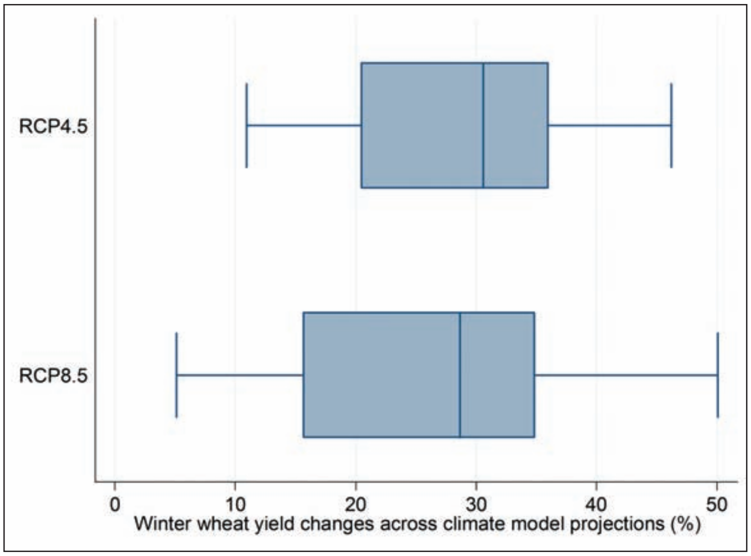

Figure 2. *Changes in winter wheat yield across climate projection models. (Note: RCP 4.5 is the lower-emission scenario, and RCP 8.5 is the higher-emission scenario.)*

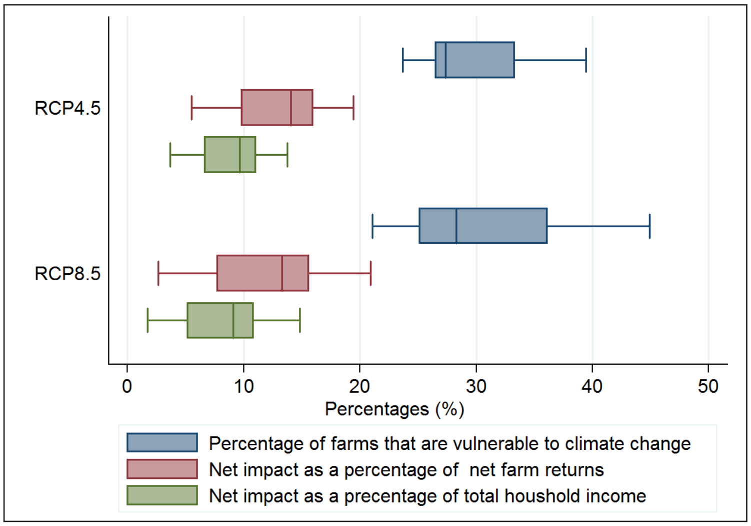

Figure 3. *Effects of climate change on the current winter wheat production system. (Note: RCP 4.5 is the lower-emission scenario, and RCP 8.5 is the higher-emission scenario.)*

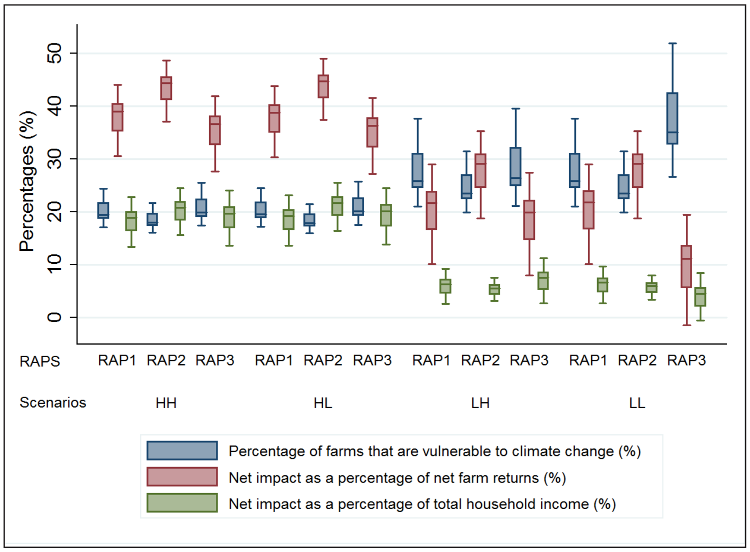

Figure 4. *Effects of climate change on the future winter wheat production system (Note: RAP = representative agricultural pathway; RAP1 = business as usual, RAP2 = dysfunctional world, RAP3 = sustainable development. HH scenario = high wheat price and high cost of production, HL scenario = high wheat price and low cost of production, LH scenario = low wheat price and high cost of production, LL scenario = low wheat price and low cost of production.)*

Agricultural productivity under future climate scenarios

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Estimates of the possible impacts of climate change on agricultural productivity range widely, depending on the crop, location, and estimation method used. For wheat in temperate regions, the recent Intergovernmental Panel on Climate Change (IPCC) assessment shows a wide range of estimates (without adaptation), ranging from a 50% decrease in productivity to a 40% increase, with the average being slightly negative (about a 5% decrease) and decreasing with increased temperature.

IMPACT

Using relative yield to study agricultural productivity improves our knowledge of assessing the impact of climate change on agriculture. This methodology bridges the division between process-based models and statistical models that assess climate change impacts.

An important limitation of many studies of climate impacts is that they simulate the impacts on yield at a small number of "representative" sites. However, data show that conditions vary substantially across most landscapes in terms of soils, climate, and other factors affecting yields. Here we report results from a method based on crop simulation models that is designed to represent this high degree of heterogeneity in conditions while controlling for possible systematic biases in simulated yields.

Methods. We developed a new methodology built on relative yield to better assess climate change impacts and predict actual crop productivity under future climates. We defined relative yield for a spatial unit such as a field, farm, or map pixel as the ratio of future yield over historical yield. We obtained these yields from a crop simulation model for future and current climates, using representative management data. Under the assumption that the systematic bias in simulated yields is similar for both current and future climates, the bias effect should be reduced by using the ratio of future over current simulated yield. Note that a relative yield with a value of 1 indicates no difference between future and current yield, while a value greater than 1 means future yields are higher and a value less than 1 means future yields are lower than current yields.

Results. We used the relative yield methodology to study the REACCH region based on projected yields from a crop simulation model called CropSyst. For this analysis, we used the projections from 14 global climate models (GCMs) under two emissions scenarios (known as representative concentration pathways): RCP 4.5 and RCP 8.5.

1. We find that climate change will likely benefit winter wheat productivity on average by increasing average relative yields in the REACCH region under most projections of future climate, but will likely lower spring pea productivity by reducing average relative yields in the annual system (Figure 1).
2. The effects of climate change on crop productivity are not uniformly distributed among farms, and due to this heterogeneity, the simulations indicate that while a majority of farms would tend to have higher yields with climate change, a substantial proportion could have lower yields (that is, would be vulnerable to yield losses) (Figures 2 and 3).

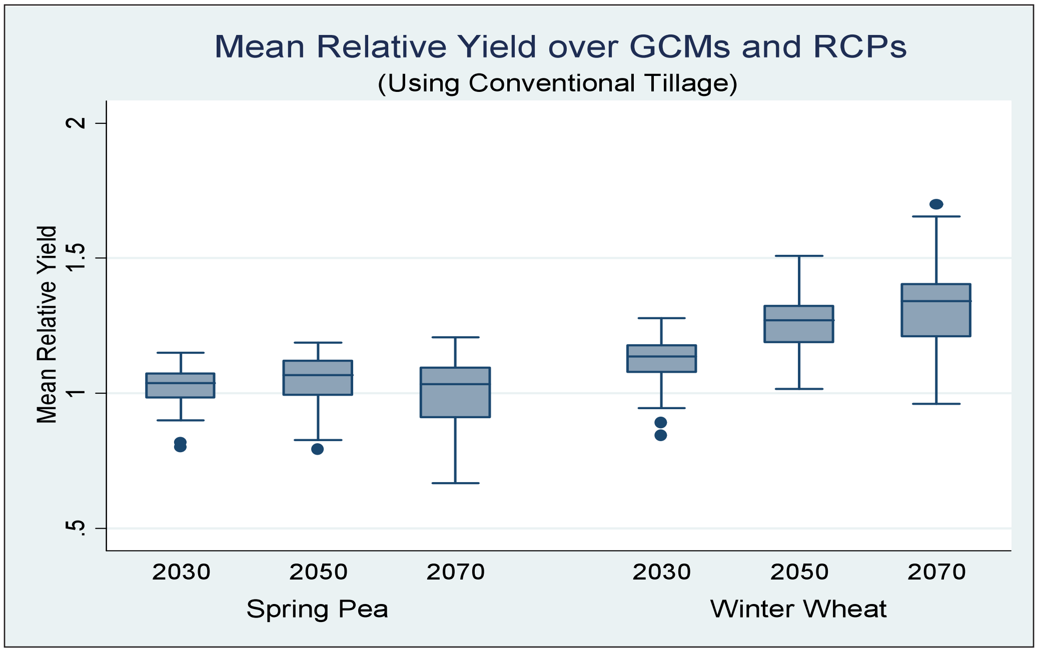


Figure 1. *Mean relative yield of spring peas and winter wheat over 14 global climate models (GCMs) and two emissions scenarios (known as representative concentration pathways, or RCPs).*

3. There is substantial uncertainty in projections of future climates, and thus there are also large uncertainties in the impacts on crop productivity. Figures 1, 2, and 3 all show that the projected distributions of relative yield in the REACCH region are substantially different for different GCMs.

Conclusions. The results from the REACCH region study show that on average, wheat producers in the region are likely to experience higher yields with future climates. However, there is substantial variation in the size of these yield gains, and at some locations losses are possible. There is also much uncertainty in the projections of future climate, which in turn means that there is substantial uncertainty about the future yield impacts.

These relative yield estimates provide growers and policy makers with information about the likely effects of climate change on productivity in the region. In related research, these yield estimates have been combined with economic data to study the likely economic impacts of these changes (see the companion article "Economic impacts of climate change on winter wheat").

In interpreting these findings, it is important to keep in mind that they do not account for important factors such as pests and disease effects of climate. Current research is addressing this limitation. Also, it is important to recognize that the results presented here do not incorporate possible adaptations to climate change. Current research is investigating adaptations and will be reported in the next REACCH annual report.

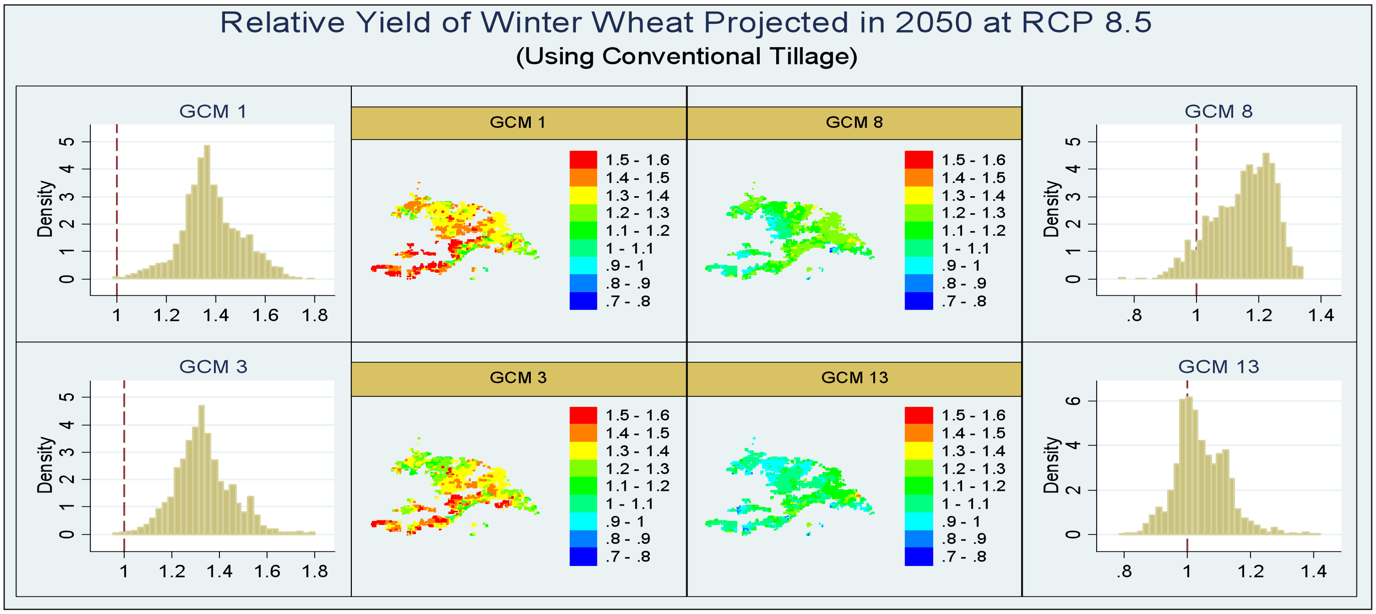


Figure 2. *Relative yield distributions of winter wheat for four global climate model (GCM) projections at representative concentration pathway (RCP) 8.5.*

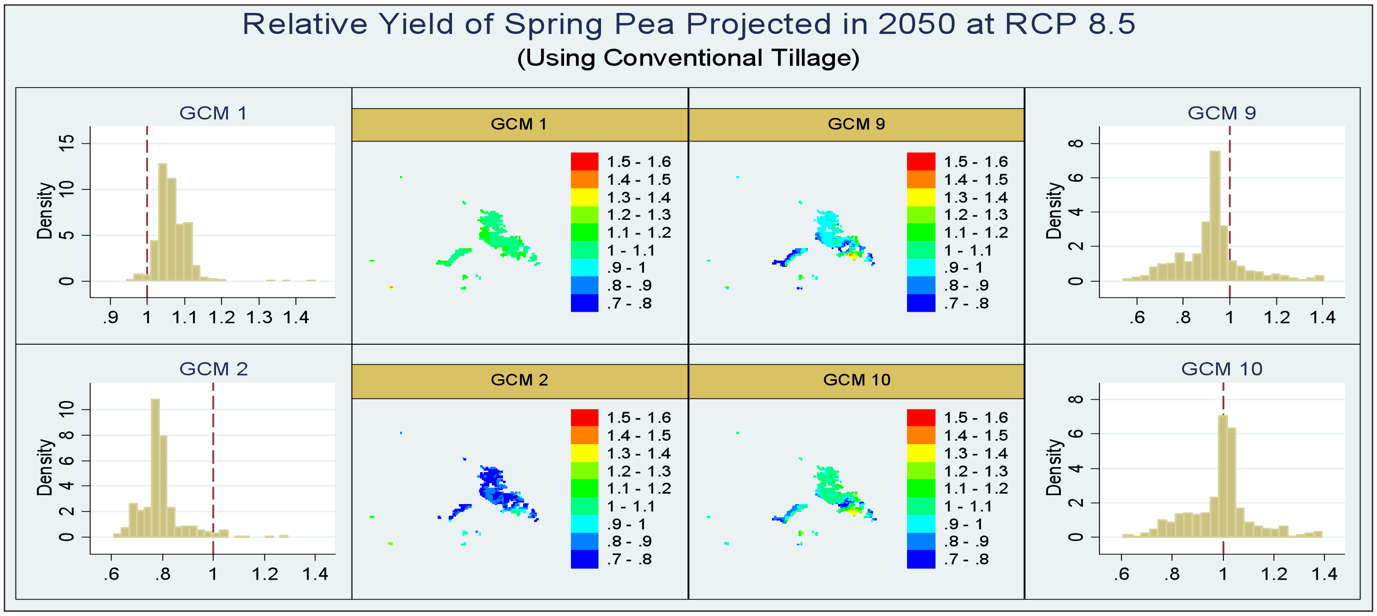


Figure 3. *Relative yield distributions of spring pea for four global climate model (GCM) projections at representative concentration pathway (RCP) 8.5.*

Using science for agricultural adaptation in the Pacific Northwest

Chad Kruger WSU, Dan Siemann Washington State Department of Natural Resources, and Jonathan Yoder WSU

The mission of REACCH is "climate science Pacific Northwest farmers can use." However, extending climate change research to farmers and land managers in order to support meaningful action is a serious challenge. Unlike many traditional problems addressed in agricultural research, where experiments and analysis lead to tangible management recommendations or technologies, climate change research generally delivers much more abstract insights about an uncertain future. For instance, although a breeder can easily recommend a wheat variety that shows disease resistance, our climate change studies report that Pacific Northwest (PNW) winter wheat yields may change by between 20% and 80% under future climate scenarios. How can a farmer use this kind of information?

IMPACT

Research into climate change often provides abstract insights into an uncertain future. A unique collaboration between scientists involved in climate change research through REACCH and other projects and the Washington State Department of Natural Resources is extending complex climate change science to support future land management decision making. Insights gained from this process are already being used in the development of resource materials that support the REACCH mission of providing "climate science Pacific Northwest farmers can use."

The Washington State Department of Natural Resources (DNR) is the largest, most geographically distributed, and most diverse agricultural landowner and manager in the state of Washington, leasing approximately 1.1 million acres of state trust cropland and rangeland to Washington farmers and ranchers (Figures 1 and 2). DNR's trust land management mission is driven first by a statutory fiduciary responsibility to generate revenue, primarily for school construction, and second by consideration for conservation and the sustainability of the trust lands. Although DNR is a public agency, its unique mission means that it is managing challenges similar to those of private land managers and farmers. Furthermore, DNR's distributed lands portfolio means that it will experience some of the same climate-induced challenges faced by farmers in the state.

Public Lands Commissioner Peter Goldmark, who is also a wheat farmer in the REACCH region, has spent considerable time pondering the question of what climate change means for agricultural land management. In 2014, Commissioner Goldmark established an Expert Council on Climate and Environmental Change to provide guidance to DNR regarding climate change vulnerability assessment and adaptation planning for state trust lands.

Scientists involved in agriculture and climate change research through the REACCH, BioEarth, and WISDM projects are working with DNR's agricultural lands management group to develop and conduct a climate change vulnerability assessment for DNR lands. The goal is to identify key resource risks and vulnerabilities as well as opportunities for strategic investment that will position DNR to improve sustainability and profitability under future climate change. This assessment will suggest approaches for climate adaptation in diverse settings and illustrate how other agricultural landowners and managers in the inland PNW can use abstract scientific results from REACCH and other climate change research to inform specific risk reduction actions and investment strategies. In short, the assessment provides PNW farmers with a helpful connection between climate research and their own management decisions.

The process is straightforward. Scientists provide general and specific information regarding regional climate change projections and the implications for agriculture in the region. DNR's agricultural management team informs the scientists of the portfolio of DNR managed agricultural lands as well as the suite of management decisions that they must make. Scientists and DNR managers discuss at length the potential climate sensitivity of specific types of land resources and management decisions and prioritize those lands and decisions that are most vulnerable or that offer the most opportunity as areas that need additional investigation.

This assessment project is not yet complete, but several lessons have already emerged:

1. There is a difference between the "science questions" and the "management questions" when it comes to the implica-

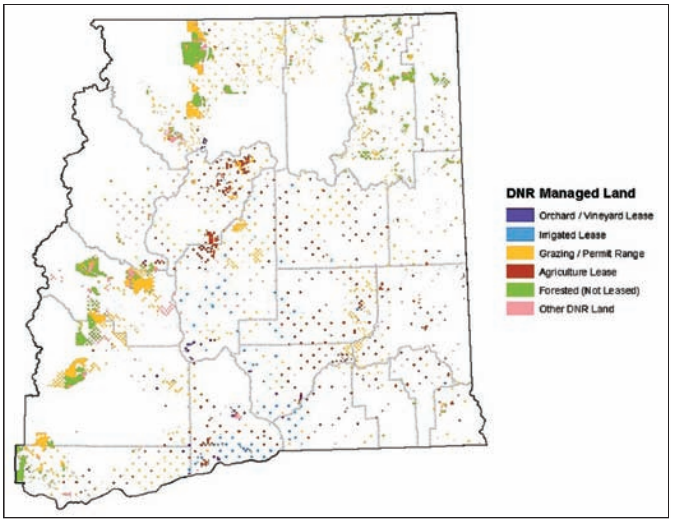


Figure 1. *Lands in eastern WA managed by the Washington State Department of Natural Resources.*

tions of climate change for agriculture. To date, most of the published research has focused on science questions, which are mostly exploratory investigations into what climate change might mean for agriculture at an aggregate level. Very little research has focused on what management decisions or adaptations may be effective for a given commodity or location. Managers would benefit from more precision in evaluating a suite of management strategies under future climate scenarios.

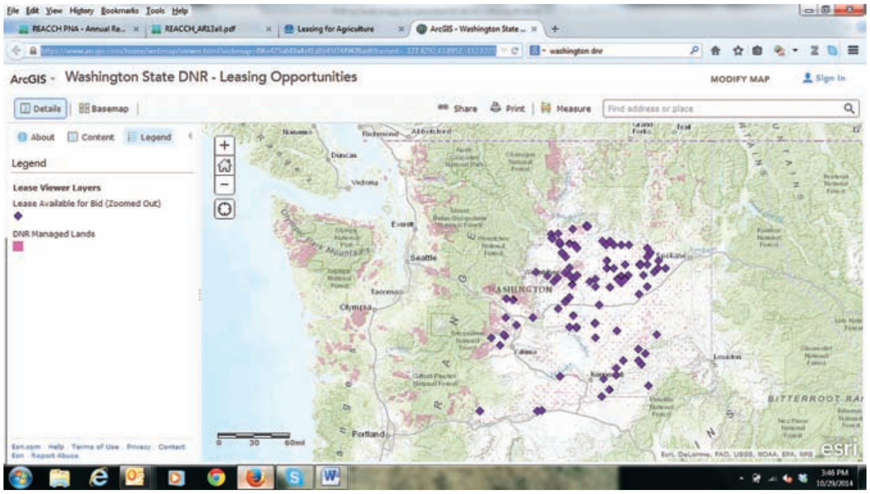


Figure 2. *Crop and grazing lease bids available from the Department of Natural Resources.*

2. In-depth explanation by DNR of the nature, processes, and constraints of management decisions has provided valuable context for identifying and translating relevant insights from available research. Understanding why and how a particular management decision is made is crucial to determining how climate-sensitive that decision might be and what research-based insights are currently available.

3. The availability of good data is a limiting factor. It is much easier to apply insights based on published research when good data are available to translate abstract research findings into specific and actionable management strategies. For instance, research indicates that climate change is likely to have significant impacts on water supplies in the region, but those impacts are highly dependent on location and existing water rights. Management and investment options abound for addressing irrigation issues, but it was DNR's robust dataset on water rights that enabled us to quickly identify climate-sensitive vulnerabilities and opportunities for water resource development. In many instances, however, insufficient data precludes current and possibly future assessment of vulnerabilities and management opportunities. Data are costly to collect and manage, but scientific insight into and assessment of adaptation effectiveness requires investment. Seeking out and exploiting cost-effective data collection opportunities can facilitate the adaptation process.

It simply isn't cost-efficient to follow this process for every farmer or landowner in the region. However, this model proved quite helpful as the architecture for designing decision support information that more farmers and land managers can use, as well as for refining a more precise set of management questions that research can inform. Insights gained from this process are already being used in the development of resource materials that support the REACCH mission of providing "climate science Pacific Northwest farmers can use."

Photo by Nita Robinson.

Using big data to inform agricultural decisions

Laurie Houston (laurie.houston@oregonstate.edu) OSU, Susan Capalbo OSU, and John Antle OSU

Making informed decisions at a farm or landscape scales is not easy. Critical information may be missing, or consequences may not be readily identifiable. Sometimes there is just too much information to process. The agricultural sector, like all parts of our global economy, is becoming data-rich, due to advances in remote and mobile measurement technologies, but it needs better data management and analytical capabilities. The relationship between land management decisions and desired economic, social, and environmental outcomes is complex, and management outcomes will benefit from coordination among land managers, researchers, and policy analysts.

IMPACT

Development of private-public partnerships could advance a new knowledge infrastructure for agriculture. Anonymized, spatially linked data could be analyzed to improve landscape management models and design smarter public policies. In return, individuals could receive input and yield information useful for reducing costs and improving yields.

Status of big data in agriculture. Increasingly, companies such as Monsanto and John Deere are offering services that allow the collection of detailed spatial and temporal data regarding planting densities, dates, production growth, and harvesting. In return, these companies promise to evaluate the data and provide participants with information aimed at increasing farm profits or net returns by optimizing input uses and improving yields. See Figures 1 and 2 for examples of precision agriculture software being used in the REACCH region.

Monsanto claims that its application of “data science” has the potential to create billions of dollars in increased farm revenues and lower costs by providing field-specific seeding and fertilizing “prescriptions.” Monsanto’s recent purchase of The Climate Corporation, a firm specializing in site-specific weather projections, has added the capability to fine-tune field-based weather predictions. These developments in software capacity are viewed by agribusiness companies as opportunities to provide services that help producers meet production challenges associated with greater variability and risk from a changing climate and changing economic conditions. Some farmers in the REACCH region are adopting precision agriculture technologies in their farming operations (Figures 1 and 2).

Next frontier for data analytics. An increase in the use of precision farming and mobile technologies and improvements in data management software offers expanding opportunities for an integrated data infrastructure linking farm management decisions to site-specific biophysical data and ultimately to the design of “climate-smart” policies. Field-specific data, combined with recommended uses of fertilizers, seeding rates, and other inputs, can be integrated with spatial landscape-scale models for fine-tuning agricultural policies. For example, better-quality data and models could enhance the targeting of incentive payments provided to farmers to improve water quality and conserve biodiversity.

So how might this work? Figure 3 provides an overview of the linkages between data and decision tools at farm and landscape scales that support science-based policy. While farm-level decision making and landscape-scale analysis have different purposes, they both benefit from the same data:

- Private data: site- and farm-specific characteristics of the land and the farm operations, and site- and farm-specific management decisions.
- Public data: weather, climate, and other physical data describing a specific location, as well as prices and other economic information.

Figure 1. *Eric Odberg, a farmer in the REACCH region, using precision agriculture software in the field. Photo by Guy Swanson.*

A key to achieving a smarter infrastructure is to recognize that new and better data are an asset to both private and public stakeholders, and can provide win-win situations for improving farm profits, the sustainability of our food and agricultural systems, and the outcomes of public policies. This requires that all participants clearly understand the mutual benefits. For example, producers should be aware that the information they and others provide will help build more effective management tools, such as prescriptive farming tools for improved yields and reduced input needs. This same information could also be used to provide the detailed data necessary for documenting organic or sustainable practices for certification, or for compliance with regulatory standards. Additionally, the spatial information will provide the data necessary to understand the relationships among management practices and outcomes for both production and conservation, as well as to document improvements in environmental quality at the landscape scale (not just on individual properties). Subsequently, this information can facilitate and enhance science-based approaches to agricultural policy.

Figure 2. *An example of precision agriculture software used in the field. The Trimble FmX controller (screen on right) can independently control the application rate of up to four products. Raven Envizio Pro (smaller screen on left) carries out auto-steering and provides guidance. Photo by Guy Swanson.*

A public-private partnership would reduce the "respondent burdens" associated with the present system of multiple mail-based and personal interview surveys used to collect data periodically from growers and landowners (such as the National Resources Inventory and the Census of Agriculture). Under an integrated system, much of the baseline information could be acquired and stored once, as a part of a farm operation's ongoing management system, rather than being collected multiple times for multiple purposes. This information could be updated in a more cost-effective way, through mobile or web-based technologies. Such partnerships would minimize the duplication of data collection efforts and costs, making science-based policies and precision agriculture more economically feasible.

Concerns to address. To make these proposed partnerships attractive to participants, key operational considerations need to be addressed. These include designing an efficient and secure data system, maintaining data confidentiality, addressing privacy concerns, and identifying reciprocal benefits.

In summary, an agricultural knowledge infrastructure would be an asset for supporting productivity gains and policy improvements. It would depend upon strong partnerships with public and private entities to ensure privacy and confidentiality, reliability, sustainability, and usefulness for onsite management as well as science-based policies. The rapid pace of advancements in tools, technologies, and data initiatives, coupled with the increasing demand for better data, provides an ideal environment for the development of partnerships to build a viable and sustained knowledge infrastructure. As big data drives ever more demands for better policies and better management, the new tools and innovations that result will shape the sustainable management of agricultural ecosystems in a very positive way.

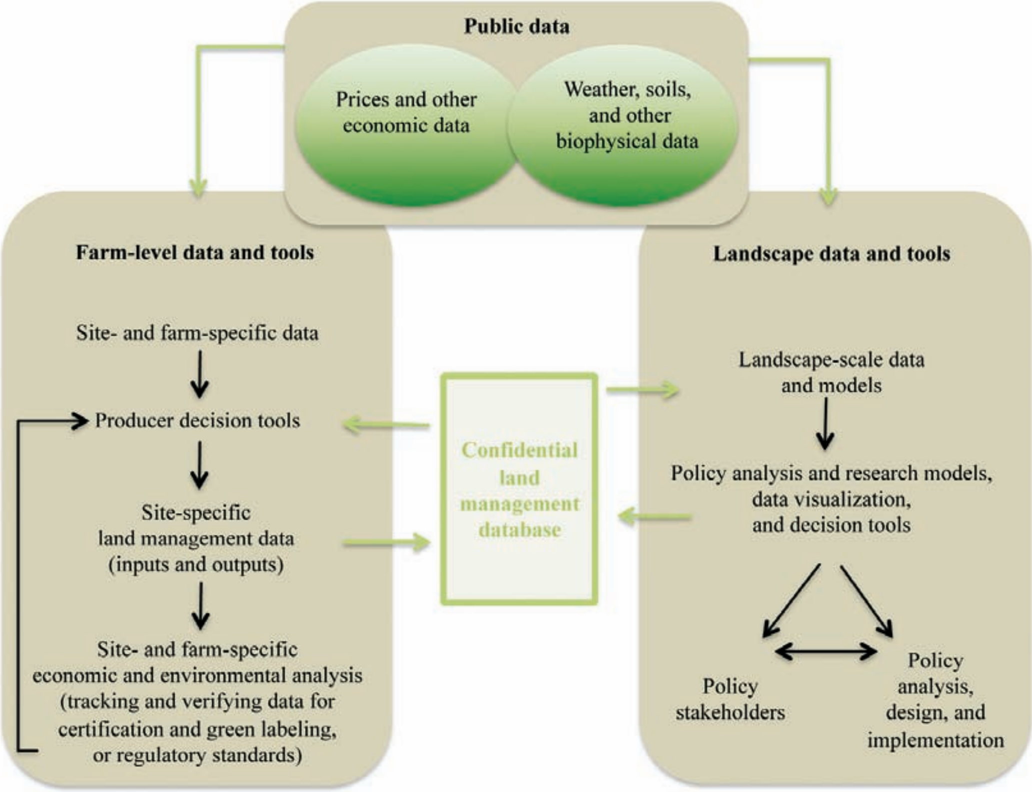


Figure 3. *Linkages between data and decision tools at farm and landscape scales.*

Using big data methods in cartography and modeling

Edward Flathers (flathers@uidaho.edu) UI, Paul Gessler UI, Erich Seamon UI, and Rick Rupp WSU

The rise of "big data" science in recent years has been of great commercial importance to major businesses such as Facebook, which applies powerful data analysis techniques to choose which advertisements to show to each user, and Netflix, which uses data about its customers' rental history to recommend movies that they might enjoy. In the REACCH project, we can use some of the same big data methods to develop a deeper understanding of our environment and agricultural systems in the Pacific Northwest. Here we describe a project in which we are using cloud services and supercomputers in combination with data collected by many different researchers to develop a system that enables us to map out the organic carbon content of the soil across our region, giving us some indication of soil health (Figure 1).

IMPACT

Developing "big data" methods for data analysis helps us to answer current questions about the REACCH study area and serves as a platform for continued study in the future.

Big data is an emerging field that describes new kinds of scientific analysis that have been enabled by recent advances in technology. Inexpensive data storage, broadband Internet connectivity, and computer processor capability come together to allow us to build larger collections of data and to transmit those collections to high-performance computer centers for analysis. This improved technology comes into play, for example, in weather forecasting—short-term weather forecasts today are much better than in the past, in part because of the powerful supercomputers that are used to model weather systems.

In the REACCH project, we are developing methods for applying these big data technologies and techniques to environmental data in ways that are easy to repeat, reuse, and repurpose for use with data that we will collect in the future. As a pilot study to drive the development of our big data tools, we are using data that describe the soils and topography of the REACCH study area to build a statistical model that produces a map of soil organic carbon in our agricultural areas. The organic carbon content of soil can give us some idea of the health of the soil and help guide decisions about the agricultural management practices that we employ in an area (Figure 2). If modeling efforts can produce data at a high enough resolution, the results could even be used to support activities like precision agriculture. Our big data process has four main components: data collection, processing, visualization, and storage.

First, we collect the data. One of the hallmarks of big data science is bringing together data from a variety of sources and assembling them into a single, large collection. In our case, REACCH researchers have collected soil from various locations in the field, taken the samples back to the lab, and measured the soil's organic carbon content. Researchers at the U.S. Department of Agriculture National Cooperative Soil Survey have made similar observations across the country and have made their data available to the public on their website. We combine these two data sources to build a dataset that has more complete coverage than either one of the original sources has on its own. We also include topographic data from the U.S. Geological Service National Elevation Dataset.

Next, we process the data. Another common practice in big data science is the use of "cloud" processing: offloading complex computations to a massive supercomputer that is shared by many clients. At the REACCH project, we can choose to process our data using the powerful supercomputer located at the Idaho National Laboratory, or we can use the Amazon Elastic Compute Cloud, among others. Our choice of a processor is influenced by how complex our model is, how busy each cloud processor is,

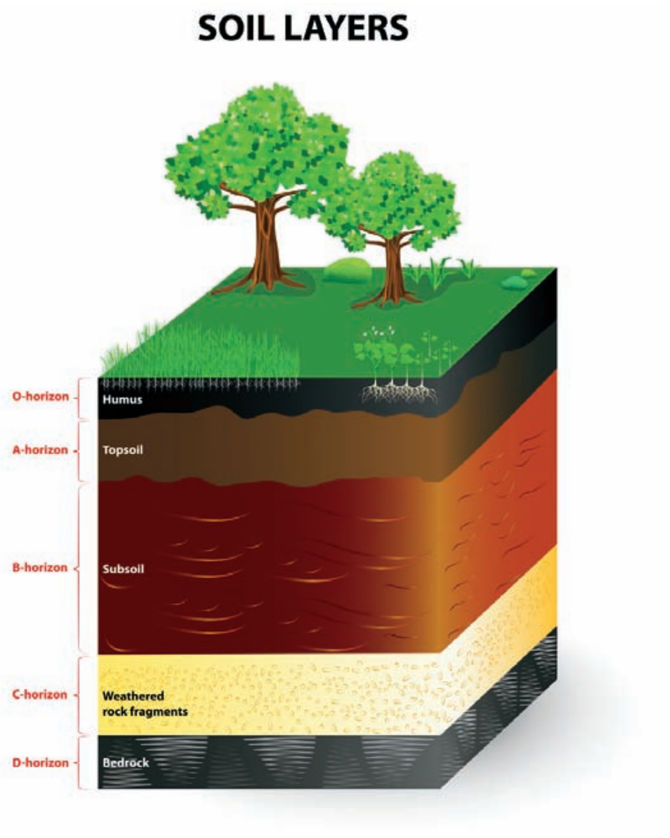


Figure 1. *Soil organic carbon is usually concentrated near the surface, where it accumulates as a product of the decay of plant matter. Image © Designua | Dreamstime.com*

Figure 2. *Soil profile from the wheat-growing area of the Pacific Northwest. Photo courtesy of UI PSES.*

how quickly we need the results, and the cost of computer time. We upload the data to the supercomputing facility for analysis, and then sit back and wait for the results to come back.

When the supercomputer is done, we get back to work. The results of our statistical model run are a large numerical data table. We import this data table into software programs that allow us to build a map of our area of interest (Figure 3). The map, in combination with the data table, can be used by crop consultants and growers to better understand the way that soil organic carbon content varies over our agricultural area, which can support them in making management decisions.

The last step in our big data process is storage. We take the input dataset that we built, the statistical model that we executed, the tabular results that we received from the supercomputer, and the map that we created, and we package it all up for storage in our long-term data library. By archiving the data and the computer code that we used to produce our results, we can ensure that we can always go back and repeat the process, perhaps using additional soil samples that have been collected, or for a different area of the country. We can also share our process with researchers at other institutions, who can help to refine the methods using their own expertise.

This soil-mapping exercise is just one example of the kinds of big data science that can be done in regional projects like REACCH. As we develop our modeling process, we prioritize the use of free, industry-standard software and methods that help us implement a system that is modular and reusable, and that can provide benefits not only to the stakeholders of REACCH, but also to other projects in the future.

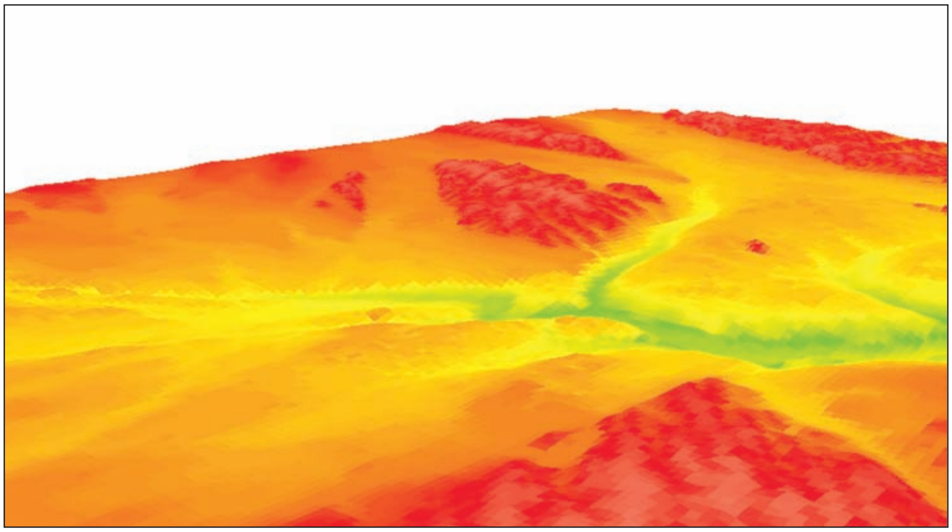


Figure 3. *A 3-D map showing approximate soil carbon concentration in an agricultural area near Umatilla, OR. Carbon migrates from erosional areas (red) to depositional areas (green) due to differences in soil composition and terrain.*

Photo by Brad Stokes.

Partnerships to support sustainable cereal production in the PNW

Sanford Eigenbrode (sanforde@uidaho.edu) UI

Although REACCH is a very large transdisciplinary project, we are benefitting from and contributing to many sorts of collaboration with other projects (Figure 1), and we depend upon support from institutions in the PNW. As the REACCH project matures, it seeks to provide a model for continued coordinated collaboration to address the sustainability of our cereal systems, not only within the geographic footprint of REACCH, but across our three states. REACCH and other federally funded projects will end, but our universities, USDA Long-term Agro-Ecosystem Research (LTAR) sites, USDA Climate Hub and anticipated new sources of federal funding can and should continue to work in a collaborative framework to ensure research, education and extension are efficient, coordinated and impactful. In the following section of this report, many of these key partners have provided overviews of their work and how it connects with REACCH now and as part of future efforts.

Photo courtesy of the Lewiston Tribune.

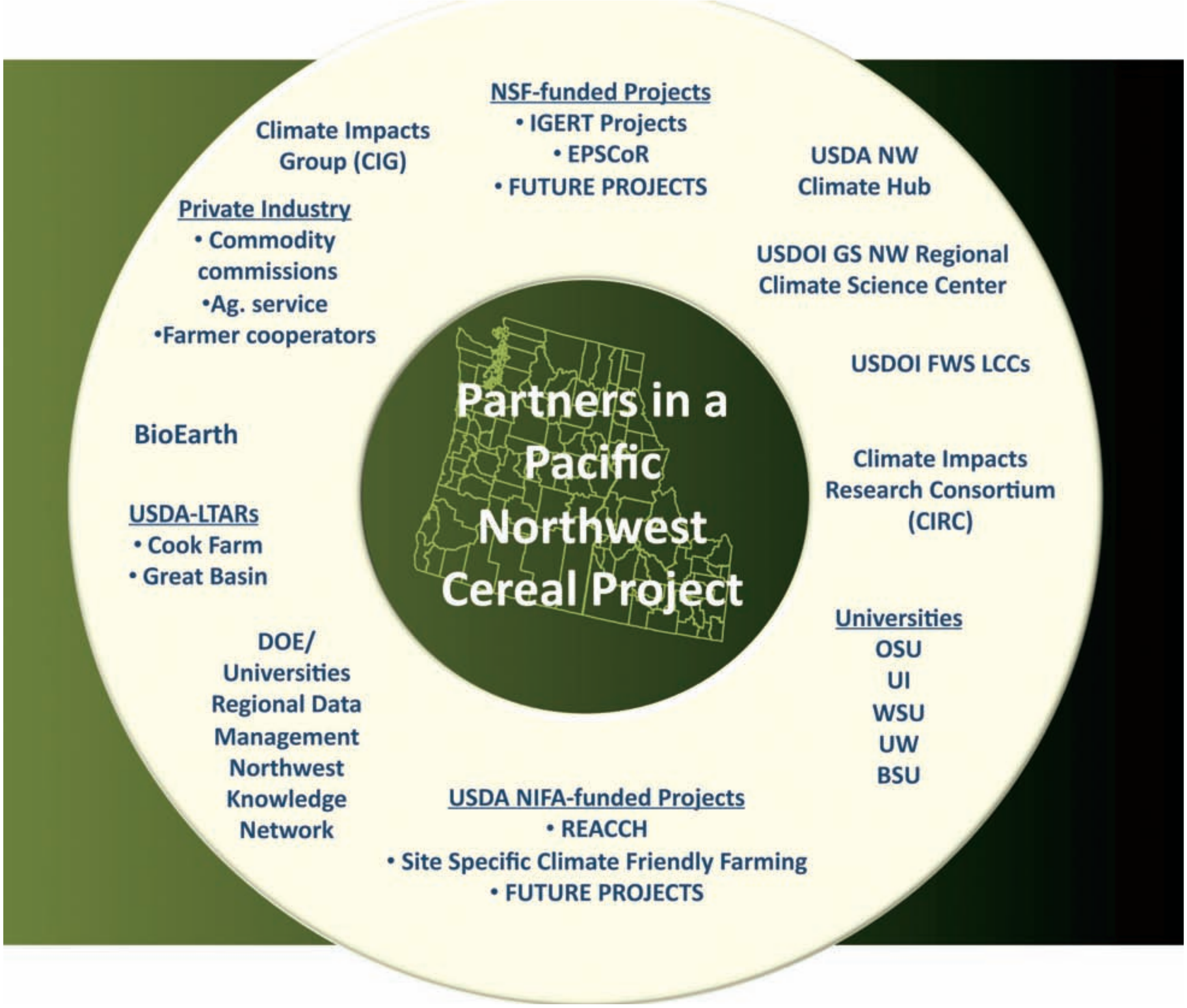


Figure 1. *A schematic showing how REACCH and other projects and activities throughout the northwest are all potential components of a cohesive long-term collaborative network that supports sustainable cereal grain production systems of the PNW.*

Building relationships with agricultural industry service providers

Kristy Borrelli (kborrelli@uidaho.edu) UI

IMPACT

Agricultural industry service providers and their associated advisors have been cited as some of the most trusted resources for regional producers. Through collaboration, REACCH intends to develop a larger network of professionals who are equipped to support sustainable farm management far into the future.

The long-term outlook of climate change often makes it difficult for land managers to have an immediate impact on existing agricultural systems. As a result, REACCH has been focusing on building the capacity of regional producers and agricultural professionals to interpret climate information and assess the associated risks and opportunities. Although these efforts extend to a large network of professionals interested in sustaining Pacific Northwest (PNW) cereal systems, we recognize that agricultural industry service providers are some of the region's producers' most trusted resources. Because of these partners' close relationships with cereal producers, we value their input and support.

Agricultural industry partners were key participants in Precision Agriculture Demonstration Day in Moscow, ID, in 2014. Commercially available field equipment enhanced with precision technologies was displayed by CHS Primeland (Figure 1) and Jones Truck and Implement, Inc. (Figure 2). Brad Ward, a pilot with Advanced Aviation Solutions, LLC, flew an unmanned aerial vehicle (UAV) and displayed the photos it captured at lunch. Representatives from Decagon Devices, Inc., demonstrated new soil probes that will soon be incorporated into research and commercial equipment, and Trimble Navigation Ltd. and AgVu Hyperspectral Imaging Services had software available for participants to interact with. Involvement by regional agribusinesses allowed field day attendees to better comprehend the connection between research and implementation of emerging technologies.

Figure 1. *CHS Primeland displays a dry fertilizer applicator equipped with precision technologies at a June field day in Moscow, ID. Photo by Leigh Bernacchi.*

Figure 2. *Jones Truck and Implement, Inc., crop consultants pose for a photo in front of an Apache sprayer at Precision Agriculture Demonstration Day. Photo by Leigh Bernacchi.*

Participation of these partners at the field day has already led to further collaboration. CHS Primeland sent 20 members of its field staff to a workshop at the University of Idaho (UI) to learn more about advancing their connection to producers with university extension resources. Brad Ward and other UAV enthusiasts participated in UI's Geographic Information System (GIS) Day to educate students and the general public about laws associated with using UAVs in agriculture.

Regional associations have long recognized the value of building relationships between universities and regional businesses. REACCH has been partnering with the Far West Agribusiness Association (FWAA) and Pacific Northwest Direct Seed Association (PNDSA) in their winter conferences and other events. Each conference brings in approximately 600 participants because both organizations are well established and respected by producers and agribusiness professionals.

Finally, the REACCH Stakeholder Advisory Committee's (SAC) 27 members consist of representatives from seven different regional agribusinesses and associations, in addition to farmers, grain commissioners, and private and state agency representatives. This group exists to offer support and advice regarding actions that affect stakeholders. Agricultural industry SAC members have served on search committees for REACCH's extension faculty and review committees for its Extension Curriculum Grant Program. They are represented at REACCH's annual meetings and participate in panels and discussions that influence the direction of the project.

Multiple experiences have facilitated agreement among all parties of the great benefit of continued collaboration among academics and industry partners. Further collaboration at field days, workshops, and conferences, as well as involvement of agricultural industry partners in scientific and outreach opportunities, will form a new model for regional agriculture programs. Building strong relationships with multiple stakeholder partners can mutually enrich our efforts to prepare farmers to manage land into the future.

Site-specific Climate-Friendly Farming

The Site-Specific Climate-Friendly Farming Team (dave.brown@wsu.edu)

The uniform application of nitrogen to spatially variable farms leads to unnecessary nitrogen losses. These losses result in a financial cost to growers and an environmental cost to society. Nitrogen fertilizers are expensive, and their manufacture contributes to global climate change. Agricultural nitrogen can be lost in the form of nitrous oxide (N_2O), a potent greenhouse gas, or nitrate (NO_3^-), a surface and groundwater pollutant. It is in the interest of both growers and society to find ways to mitigate agricultural nitrogen losses through precision management.

IMPACT

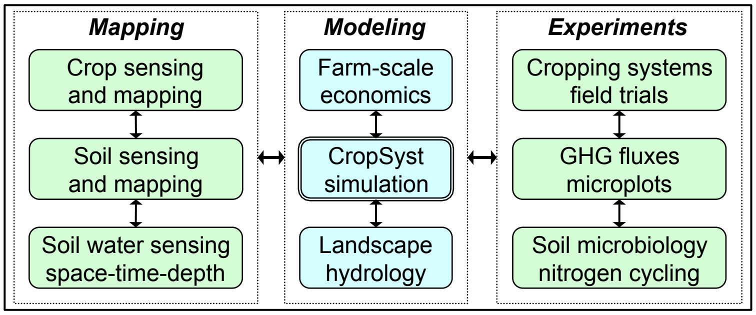
Nitrogen losses can result in a financial cost to growers and an environmental cost to society. Precision agricultural technologies can help wheat growers better understand their fields and manage N fertilizers more efficiently across non-uniform landscapes and reduce losses.

The Site-Specific Climate-Friendly Farming (SCF) project team is tackling these problems in two primary ways: (1) we seek to improve our understanding of the spatial and temporal variability of nitrogen cycling, N_2O emissions, and related processes for wheat-based cropping systems on complex Palouse landscapes (Figure 1); and (2) we are constructing site-specific management tools to help farmers reduce nitrogen losses, improve nitrogen use efficiency, and increase profits. The availability, uptake, and movement of water, as controlled by topography and soil properties, is the driving force behind the spatial variability of the nitrogen cycle, so mapping the agrohydrology of the Palouse is central to improving management.

SCF project activities can be loosely grouped into three areas: mapping, modeling, and experiments (Figure 2). Using a variety of crop, soil, and moisture sensors, we are developing approaches to inexpensively map and monitor soil, water, and nutrient variability over space and time. We are also refining and linking models to simulate crop response to a variety of climatic and management scenarios, and evaluate the economic consequences of grower decisions. These models are informed by a variety of experiments: (a) cropping systems experiments evaluating the effects of seeding density and nitrogen fertilizer levels for different landscape positions; (b) automated chamber experiments to measure greenhouse gas fluxes (CO_2 and N_2O) under different carbon, fertilizer, and water treatments; and (c) field and laboratory experiments to characterize the spatial and temporal variability of soil microbial processes and nitrogen cycling in Palouse wheat fields.

Advances in crop and soil sensing and mapping techniques are particularly important for growers wanting to adopt site-specific management. Mapping advances allow us to transfer the knowledge gained from experiments and modeling to new fields, without having to extensively sample and analyze crops and

Figure 1. *Research site near Colfax, WA with highly variable soils, hydrology, topography and crop productivity. Photo by Dave Brown.*



SCF
Site-specific Climate-friendly Farming

Figure 2. *Site-Specific Climate-Friendly Farming project overview.*

soils. Two main soil sensing devices are being refined for use on the Palouse: a visible and near-infrared (VisNIR) penetrometer and an electromagnetic induction (EMI) sensor. The VisNIR penetrometer allows us to probe down into the soil and measure reflectance without sampling, while simultaneously measuring the physical resistance of the soil. The VisNIR reflectance data can be used to estimate clay, mineralogy, and organic matter, while tip resistance is related to bulk density and clay content. An EMI survey estimating apparent soil electrical conductivity (ECa) can be used to map clay and water content and salinity. Figure 3 provides an example soil map for a research site near Leland, ID, showing soil resistance by depth, important for mapping root- and water-restricting soil layers. We generated this map using a detailed VisNIR penetrometer survey (50 meters [164 feet] grid) that was interpolated using EMI data. A map of estimated nitrogen balance for the same field was derived from a RapidEye satellite image (Figure 4). The availability of the red-edge band with RapidEye, allowing the computation of the Normalized Difference Red Edge (NDRE) index, has proven particularly valuable for estimating and mapping crop nitrogen content.

There is substantial collaboration between REACCH and SCF researchers. Both projects are funded by the same U.S. Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA) Climate Change program, both projects are funded over the same five-year period, and a number of co-investigators contribute to both the REACCH and SCF project teams. The projects have shared expenses and expertise in conducting joint experiments with automated chambers to measure greenhouse gas fluxes under variable levels of nitrogen fertilization, carbon amendments, and water applications (see “Nitrification and denitrification pools of N_2O: Acetylene inhibition study” on page 66 of this report). SCF remote sensing scientists have contributed instrumentation and expertise to monitor a REACCH experimental site. Perhaps most importantly, the REACCH project has the funding and personnel to disseminate SCF findings to growers and the general public. For example, in the past year SCF and REACCH have collaborated on a precision agriculture field day and an article highlighting research on the farm of SCF cooperator Eric Odberg. We anticipate ongoing collaborations on research and dissemination of SCF knowledge through REACCH education and outreach capabilities.

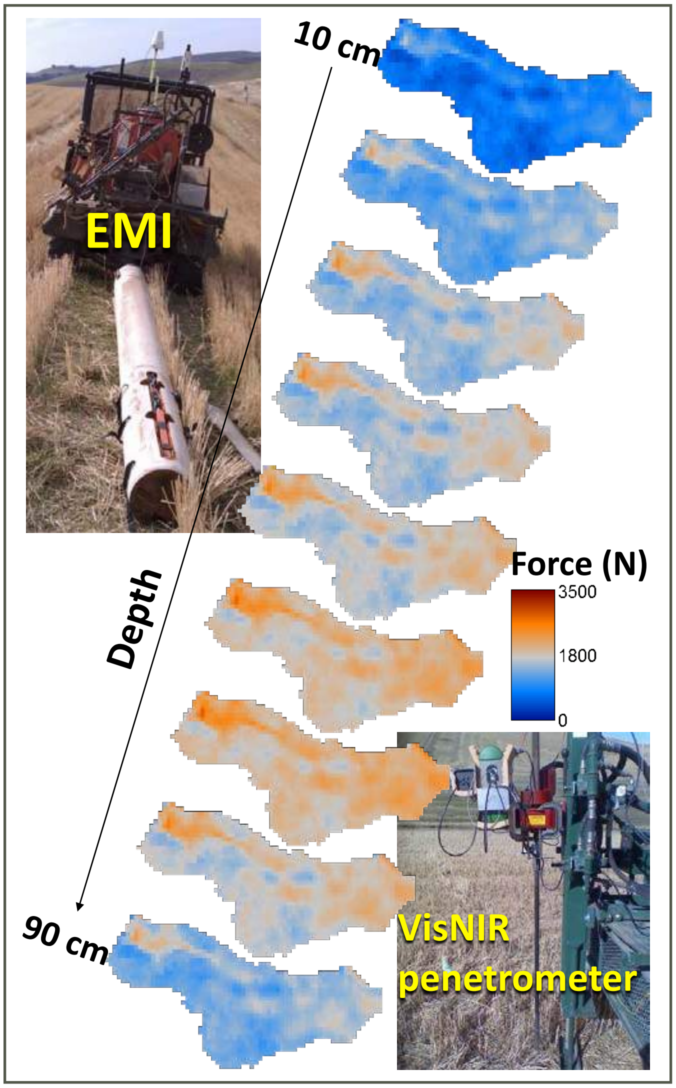


Figure 3. *Soil resistance by depth for Leland site, mapped using Visible and Near-Infrared (VisNIR) penetrometer and Electromagnetic Inductance sensor. Figures by Matteo Poggio and Caley Gasch.*

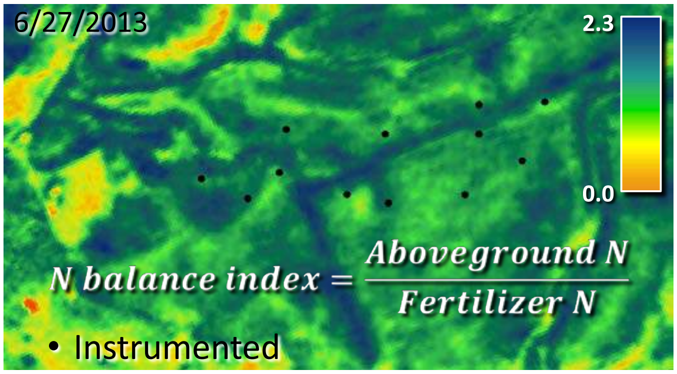


Figure 4. *Map of nitrogen balance estimated from June 27, 2013 RapidEye Normalized Difference Red Edge (NDRE) index for a field near Leland, ID (Image courtesy of Troy Magney). Notice the high nitrogen balance (blue) along old fence lines only recently removed with a right angle in the middle of the image. The red dots highlight instrumented locations within the study catchment. Figure by Troy Magney.*

Highlights from the BioEarth project

BioEarth team (jcadam@wsu.edu)

For more information, visit bioearth.wsu.edu/

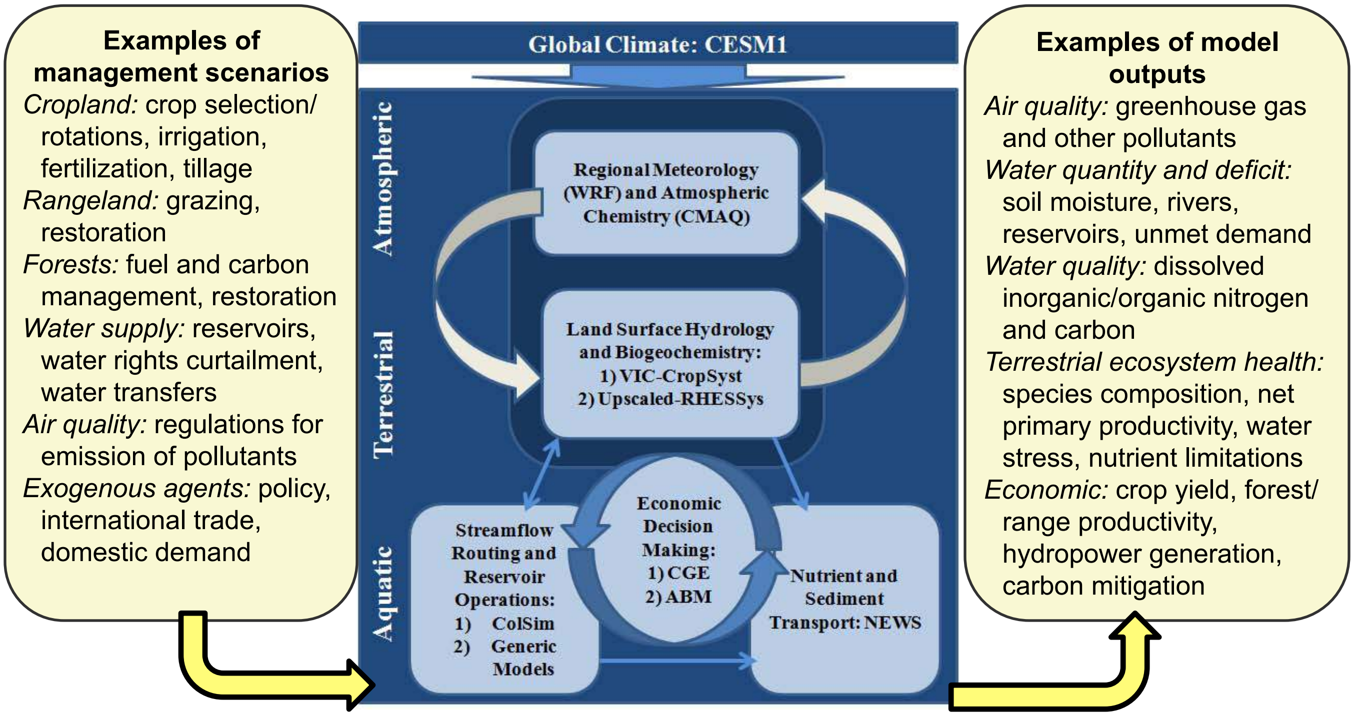
IMPACT

While not intended specifically to be a decision support tool, the BioEarth framework provides a context for evaluating various management scenarios by highlighting environmental and economic trade-offs and feedback to inform a variety of decision makers with different priorities, concerns, and constraints. Because of its large scope, the project lends itself well to partnering with existing or new initiatives focused on agricultural and environmental sustainability.

How will our actions today affect our earth's systems into the future? Humans and the earth's natural resources have been interacting for millennia and will continue to do so into the future. The overarching goals of the BioEarth project at Washington State University are to improve our understanding of the dynamics between coupled carbon, nitrogen, and water (C:N:H_2O) and human actions at the regional and decadal scales under global climate change in order to (1) better understand the impact that resource management has on earth system dynamics and (2) inform resource managers about the consequences their decisions have for the earth system. To accomplish these goals, we are developing a modular integrated modeling framework that will allow researchers to investigate how changes in climate, policy, water infrastructure, and agricultural management practices (in cropping, forest, and rangeland systems) will affect the overall earth system in the Pacific Northwest (PNW) region (Figure 1).

One key output involves the ability to incorporate cropping system management (e.g., crop selection, planting date, and irrigation technology and management) into an earth system model that allows us to investigate the interplay among climate change and variability, hydrology, water resources management, cropping system management, and crop growth and phenology (for more than 40 crop types) at a regional scale. Results for the 2030s indicate that the net effect of climate change on crop yield is highly dependent on the crop type, whether or not it is irrigated, and the degree to which water rights are curtailed during drought years, although not always in anticipated ways. Our team is investigating a variety of strategies producers across the PNW may use for adapting to climate change and its associated impacts.

Photo by Nita Robinson.



Examples of management scenarios

Cropland: crop selection/ rotations, irrigation, fertilization, tillage
Rangeland: grazing, restoration
Forests: fuel and carbon management, restoration
Water supply: reservoirs, water rights curtailment, water transfers
Air quality: regulations for emission of pollutants
Exogenous agents: policy, international trade, domestic demand

Examples of model outputs

Air quality: greenhouse gas and other pollutants
Water quantity and deficit: soil moisture, rivers, reservoirs, unmet demand
Water quality: dissolved inorganic/organic nitrogen and carbon
Terrestrial ecosystem health: species composition, net primary productivity, water stress, nutrient limitations
Economic: crop yield, forest/ range productivity, hydropower generation, carbon mitigation

Figure 1. *Linkages between the atmospheric, terrestrial, aquatic, and economic components that make up the BioEarth model, as well as examples of management scenarios and model outputs that can be explored with this framework.*

Because of agriculture's role as a source of reactive nitrogen, faculty and students are also actively investigating the sources, transport, fate, and impacts of nitrogen between the atmosphere and biosphere in the PNW. For example, we have used the National Atmospheric Deposition Program (NADP) to demonstrate that 46% to 53% of variation in wet nitrogen deposition in the Rocky Mountains, the Gulf Coast, and near the Great Lakes can be explained by El Niño Southern Oscillation (ENSO) activity. We are also refining, upscaling, and applying the RHESSys ecohydrologic model over managed forests and rangelands. Although RHESSys is intended for fine-resolution catchment studies, we are developing a decision tree to determine (for each biome and research question) when upscaling the model is defensible to reduce computational requirements. This decision tree will enable improved C:N:H_2O modeling with respect to natural and agricultural resource management activities within the context of coupled earth system dynamics.

The BioEarth project's approach to stakeholder engagement involves a series of six issue-based workshops to learn from regional natural resource managers; five of these workshops have been completed. Different stakeholder groups have diverse levels of experience with environmental models and climate science, and their information needs vary widely. Demonstrating tangible sample model outputs helps stakeholders understand the scope and scale of model outputs that are possible. There is widespread demand for online tools that enable users to synthesize the results from research efforts across the region and that provide a forum for stakeholders to ask questions of researchers. The BioEarth and REACCH teams are linked in that they are both grappling with the question of how to sustain agriculture in the PNW while minimizing the effects on the environment. Project cross-fertilization is occurring through sharing of models and data, as well through findings from our stakeholder engagement efforts.

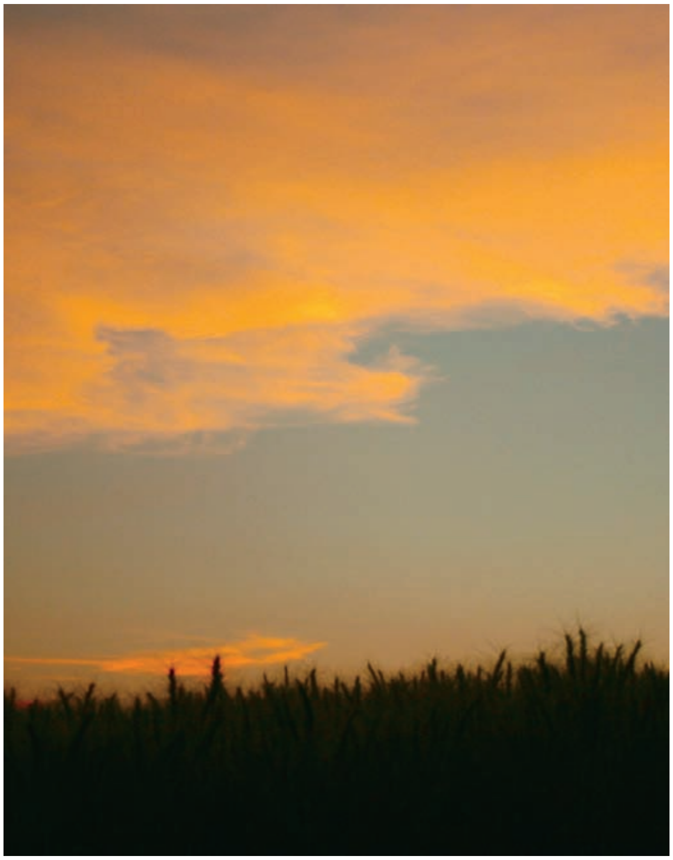


Photo by Brad Stokes.

Expanding regional outreach: REACCH extension curriculum grants

Kristy Borrelli (kborrelli@uidaho.edu) UI

Effective communication and outreach products can help local producers make informed decisions and be better prepared to manage environmental risks associated with agriculture. The geographic range and scope of interests associated with cereal-based cropping systems in the inland Pacific Northwest (PNW) require that an extensive network of stakeholders who manage, regulate, advise, and care for agricultural land, work together to address producers' needs. To facilitate these interactions and thoroughly represent regional knowledge, REACCH extension supports outreach efforts through an Extension Curriculum Grants Program. To date, the program has provided nearly $122,000 in support to researchers, extension personnel, conservation districts, graduate students, and post-doctoral students, and will continue to do so until the end of the project. The following is a summary of ongoing projects; final products are available where noted.

IMPACT

By providing support for outreach and extension throughout the Pacific Northwest, we will be able to provide growers and land managers with relevant, ready-to-use information that may not be addressed in REACCH, and strengthen the relationship among regional agricultural professionals.

Advancing nitrogen use efficiency and direct seed farming methods

Researcher: Aaron Esser (aarons@wsu.edu) WSU

Efficient use of nitrogen fertilizers by cereal crops is a primary concern for no-till producers as they strive to balance on-farm profits with environmental losses, but monitoring nitrogen use can be difficult. Two online calculators are available that help growers calculate (1) recommended nitrogen inputs and (2) post-harvest nitrogen efficiency, to assist them in monitoring nitrogen use in the field. Users can calculate nitrogen use efficiency (NUE), make fertilizer application decisions, and implement methods to improve NUE. Calculators are available at:

wheattools.wsu.edu/Applications/Fertilizer%20Use%20Calculator/NitrogenRecommendation

wheattools.wsu.edu/Applications/Fertilizer%20Use%20Calculator/PostHarvestEfficiency

WSU Dryland Wheat Nitrogen Fertilizer Calculator For more information WSU EB1987E

* denotes required input fields

Grower:
Rainfall Zone: Select type of rainfall zone
Assisted by:
Tract:
Crop: * Select type of crop
Field Description:
Date:
Soil type:
Field size: acres

Input the following to calculate the recommended nitrogen:

Soil test result unit: ● lbs/acre ○ ppm

Estimate average yield: bu/ac

Online tools can assist growers to manage nitrogen more efficiently by calculating inputs before and after harvest.

Farmer-to-farmer case study series: Increasing resilience among farmers in the inland Pacific Northwest

Researchers: Georgine Yorgey (yorgey@wsu.edu) WSU, Sylvia Kantor WSU, Kate Painter UI, Leigh Bernacchi UI, and Hilary Davis UI

Strategies for managing unprecedented risks associated with climate change can be learned from growers currently managing similar risks. This research has created case study videos and written materials that feature regional producers and focus on strategies that enhance environmental and economic resilience of cereal-based cropping systems across PNW agroecological zones. Highlighted adaptation practices include variable-rate nitrogen application, flex cropping to optimize soil moisture, diversified crops and rotations, use of cover crops, managing water deficiencies, and tillage practices and residue management. Two rounds of case studies were funded; completed materials are available at www.casestudies.reacchpna.org/.

Wheat industry's climate change communication strategy: A data-driven decision tool

Researchers: Leigh Bernacchi (lbernacchi@uidaho.edu) UI, and J. D. Wulfhorst UI

Certified crop advisors (CCAs), serving between producers and input industries, were identified as the most trusted source for information about management strategies and climate change. What CCAs need to know about their region's producers and their perspectives on climate change has informed the development of a web-based, data-driven decision tool. This tool provides recommendations for climate change communication strategies and enables CCAs to view the REACCH Agricultural Producer Survey data by generalized location. Use of this tool will improve climate change communication and information strategies among multiple stakeholders and others.

Ammonia volatilization associated with cereal production in inland OR and WA

Researchers: Donald Horneck (don.horneck@oregonstate.edu) OSU, and Marvin Butler OSU

Nitrogen loss through ammonia volatilization is a matter for concern when incorporating urea and anhydrous ammonia fertilizers into the soil is not an option. Information about chemical additives (e.g., Agrotain) that inhibit nitrogen transformation and losses will be presented in publications and grower-based talks. Publications will be in both digital and printed format and will target wheat producers, industry representatives, and their affiliates. Grower presentations will be hosted in OR, ID, and WA. Assisting regional wheat growers to make better nutrient management decisions can help reduce the negative consequences associated with nitrogen loss.

Cover crop feasibility with livestock integration in low-rainfall summer-fallow region

Researchers: Leslie Michel (LeslieM@okanogancd.org) Okanogan Conservation District, and Dale Whaley WSU

Cover crops have the potential to benefit agronomic systems but are difficult to maintain in moisture-limited regions. Suitable varieties of cover crops, planting and termination dates, and soil moisture data specific to a dryland summer-fallow region (Okanogan County, WA) will be featured in an extension fact sheet. Regional farmers will enhance their knowledge of and success for adapting cover crops to low-rainfall farming systems, particularly those that incorporate cattle, at winter meetings and a field day at grower-cooperator on-farm trials. Preliminary research supported by REACCH has resulted in continued support of this project from a U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Conservation Innovation Grant.

Resistance to wheat aphids and the effect of climatic conditions on aphid populations and natural enemies

Researchers: Silvia Rondon OSU, Mary Corp OSU, Steve Van Vleet WSU, Aymeric Goyer OSU, and Qamar Zeb OSU

Changes in climate and loss of crop resistance could affect the status of agricultural pests. Lack of new chemistries could make aphids difficult to control, but tolerant or resistant wheat varieties may help reduce aphid damage and pesticide use. Research results will be presented in an extension fact sheet and at multiple meetings to help growers learn more about insect-plant relationships and enable them to identify aphid-resistant wheat varieties. Effective management strategies could lead to reduced pesticide use and resistance in pests.

Cover crops with direct-seed wheat rotation in north central ID

Researchers: Ken Hart UI, Jim Church UI, Doug Finkelnburg UI, Kevin Seitz USDA NRCS, Vern McMaster Lewis County Soil Conservation District, and Ed Bechinski UI

Researchers are investigating the use of fall- and spring-seeded cover crop pastures in rotation with direct-seeded winter wheat in northern ID. Funding supports extension activities for ongoing research. Livestock producers will learn about the potential to extend their grazing season using cover crops at field days, demonstration trials, and grower-cooperator farm sites. Through live presentations and written outreach materials, growers will learn about cover crop yield, forage quality, soil nutrients, pH, soil ecology, and wheat yield following a cover crop.

Wireworm species diversity and distribution in southern ID

Researchers: Arash Rashad (arashed@uidaho.edu) UI, and Juliet Marshall UI

Wireworms are a significant pest for PNW wheat producers, and more information about different species and their ecology can assist with control. This research will quantify species composition and distribution in relation to southern ID environmental variables. Grower cooperation and involvement will aid in the development of a digital distribution map of ID's most common wireworm species. The map will be featured on websites and in written handouts and other publications. Wheat and barley growers, as well as extension educators and crop advisors, will learn to effectively monitor and control wireworms.

Economic injury levels and a binomial sequential sampling plan for an invasive wheat aphid (*Metopolophium festucae cerealium*) and a readily abundant wheat aphid (*Rhopalosiphum padi*) on spring wheat

Researchers: Brad Stokes (bstokes@uidaho.edu) UI, and Sanford Eigenbrode UI

Economic injury levels (EILs) aid in integrated pest management by helping growers know when to control a specific pest. Current EILs for two aphid pests are out of date or unknown. This research will identify and update EILs and incorporate them into a decision support tool that wheat producers can use to quickly sample fields and determine whether or not to use a pest control tactic. Use of this tool will help wheat producers effectively manage aphid pests.

TGet information on high-residue farming under irrigation into farmers' hands

Researcher: Andy McGuire (andrew.mcguire@wsu.edu) WSU

While high-residue cereal farming practices have existed for many years in dryland regions, they are relatively new in irrigated systems. A series of five publications, (1) What and why: Benefits and challenges of high-residue farming; (2) Crop rotations: Crops, sequences, and special considerations; (3) Residue management: How to drill, plant, and fertilize; (4) Pest management considerations; and (5) Strip-tillage: Benefits, challenges, and implementation, will be combined into one comprehensive booklet focused on the irrigated Columbia Basin region in OR and WA. In combination with workshops and conferences, the booklets will increase grower awareness of high-residue farming opportunities and help support their adoption of these systems in irrigated regions.

Aphid research is demonstrated at an OSU wheat field day in Hermiston, OR. Photo by Silvia Rondon.

A key REACCH partner for data management and the public web interface

Northwest Knowledge Network team (paulg@uidaho.edu)
For more information, visit www.northwestknowledge.net

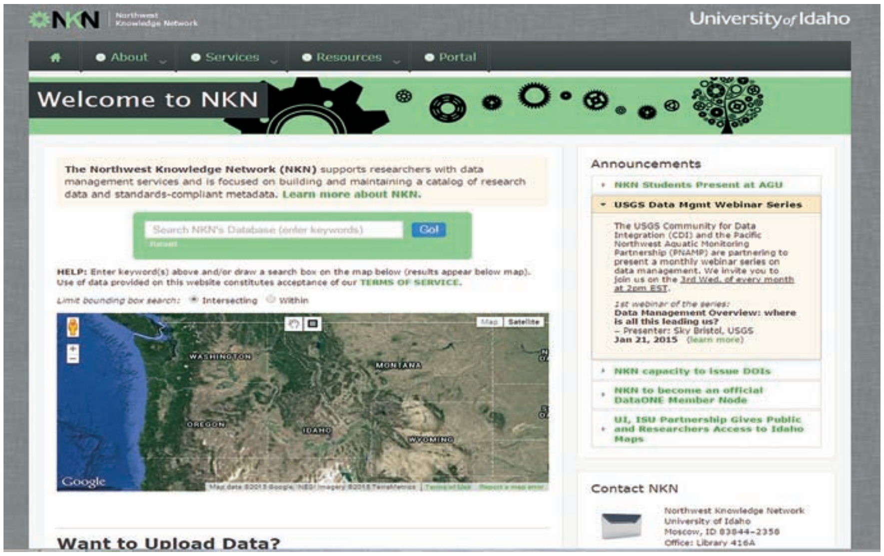
The Northwest Knowledge Network (NKN) is a unit in the University of Idaho's Office of Research and Economic Development that provides support for data management and cyberinfrastructure requirements for research projects (Figure 1). The REACCH project depends heavily on NKN support for all of its data storage, software applications, data security, and website and content. Although the REACCH research teams and project scientists typically use the website only for presenting active content to the world, NKN operates behind the scenes to support these efforts and to help things run smoothly. Along with hardware and software components, NKN also provides personnel support via access to programmers and web developers that help the REACCH environmental data manager and project scientists manage and distribute information via the REACCH website (www.reacchpna.org).

IMPACT

The data, products, and science of the REACCH program depend heavily on a partnership between REACCH and the University of Idaho's Northwest Knowledge Network (NKN). NKN ensures the smooth and secure functioning of the REACCH website and data portal and will play a key role in preserving all the outcomes of the REACCH effort.

Other support elements that NKN provides to REACCH include login and password management for REACCH team members and implementation of basic security protocols for the REACCH data-sharing policy that all REACCH researchers must sign. NKN maintains all the REACCH resources in a data center that is located in the University of Idaho library, where the NKN team resides. NKN also provides regularly scheduled automated backup of all REACCH servers, data, and web content to a mirrored site at the Idaho National Laboratory data center in Idaho Falls, ID. This ensures that if any sort of natural disaster, power outage, or computer hacker breach were to affect the REACCH servers, we would be able to restore them and continue functioning with little or no impact to the REACCH website and associated applications.

Finally, NKN is working hand in hand with the REACCH environmental data manager and the REACCH data management team to plan for the eventual transition of the REACCH website and all associated REACCH data at the end of the five-year project. This will ensure that the research publications, presentations, bulletins, communications, and supporting data will continue to be accessible beyond the end of the project. Likewise, the field data, derived products, and applications that have been developed to access and use REACCH data will continue to be available to both scientists and the public. These data, products, and publications will become a critical legacy of the REACCH effort that can continue to be accessed and developed in association with current and future projects within the region. This strategy, which depends heavily on the NKN-REACCH partnership, will help ensure that the outcomes of the REACCH initiative are not the end but the beginning of efforts to bring the best data and science to bear on the potential impacts of climate change and mitigation strategies to help Pacific Northwest agriculture.



The Northwest Knowledge Network (NKN) supports researchers with data management services and is focused on building and maintaining a catalog of research data and standards-compliant metadata. Learn more about NKN.

Search NKN's Database (enter keywords)

HELP: Enter keyword(s) above and/or draw a search box on the map below (results appear below map). Use of data provided on this website constitutes acceptance of our TERMS OF SERVICE.

Limit bounding box search: ● Intersecting ○ Within

- NKN Students Present at AGU
- USGS Data Mgmt Webinar Series

  The USGS Community for Data Integration (CDI) and the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) are partnering to present a monthly webinar series on data management. We invite you to join us on the 3rd Wed. of every month at 2pm EST.

  1st webinar of the series:
  Data Management Overview: where is all this leading us?
  – Presenter: Sky Bristol, USGS
  Jan 21, 2015 (learn more)
- NKN capacity to issue DOIs
- NKN to become an official DataONE Member Node
- UI, ISU Partnership Gives Public and Researchers Access to Idaho Maps

Northwest Knowledge Network
University of Idaho
Moscow, ID 83844-2358
Office: Library 416A

The Northwest Knowledge Network (NKN) supports REACCH and other researchers with data management services and is focused on building and maintaining a catalog of research data and standards-compliant metadata.

Northwest Climate Science Center

Steve Daley-Laursen (stevendl@uidah.edu), UI Principal Investigator Northwest Climate Science Center

The Northwest Climate Science Center (NW CSC), established in 2010, is one of eight regional Climate Science Centers initiated by the National Climate Change and Wildlife Science Center (NCCWSC) at the U.S. Geological Survey (USGS), part of the Department of the Interior. The NW CSC's mission is to coordinate the expertise of federal and university scientists to provide the scientific information and tools necessary to address the priorities of federal, state, and tribal resource managers in response to a changing climate. It is a partnership of the USGS and a consortium of three academic institutions, Oregon State University (OSU), University of Idaho (UI), and University of Washington (UW). The universities offer capabilities in climate science, ecology, impact assessment, modeling, and advanced information technology, all of which are necessary to address and respond to climate change in the Pacific Northwest. The NW CSC partnership provides an opportunity to strategically address science issues of regional significance by purposely blending recognized academic expertise and federal resources.

IMPACT

The Northwest Climate Science Center provides actionable climate science and decision support tools that will inform conservation and resource management across the Pacific Northwest. It does this by providing leadership to strengthen the region's coordinated climate science portfolio and by providing regional audiences with necessary tools and information to promote climate change awareness.

University co-project investigators for the NW CSC and REACCH are colocated at OSU and UI, and some are funded by both the NW CSC and REACCH. Planning and implementation of science, education, communication, and data management agendas are often interrelated, mutually supportive, and interactive.

The NW CSC has a stakeholder-driven science agenda with annual science priorities, and releases each year a competitive request for proposals (RFP) for climate research projects throughout the three-state region. NW CSC research focuses primarily on public forest lands and rangelands, waters, and shorelines, and supports decision makers who are responsible for these resources, while REACCH focuses on private agricultural lands and industry managers. However, research projects resulting in downscaled climate data are mutually beneficial as they produce results and data for all lands and waters in the region.

REACCH and the NW CSC use the same data management services provider, the Northwest Knowledge Network based at UI, so all data collected in research projects are stored and managed for access in a common repository. The two projects employ data management experts who work closely together on the development of metadata, policies and portals, and tools and applications for other researchers, end users, and stakeholders.

This image represents the breadth of the Northwest Climate Science Center (NW CSC) across disciplines and geography. The NW CSC combines academic expertise with federal resources to advance climate science development and delivery for managers and policy makers in the Pacific Northwest.

The NW CSC and REACCH share a common interest in preparing the next generation of climate-ready researchers and managers. The NW CSC conducts an annual Climate Boot Camp, a weeklong intensive educational program for early career professionals, including CSC graduate student fellows, cultural and natural resource managers from federal and state agencies, nonprofits, and Native American tribes. Modules are offered on climate science basics, science communications, knowledge integration, and climate adaptation on the ground. REACCH education staff have attended the Climate Boot Camp and then conducted a mini-version of the program for REACCH graduate students. REACCH and NW CSC graduate students have interacted about their research and outreach efforts at the annual Pacific Northwest Climate Science Conference, an event cosponsored by REACCH and the NW CSC.

Photo by Nita Robinson.

Pacific Northwest Direct Seed Association's partnership with REACCH

Kay Meyer (pndsa@directseed.org), Executive Director, Pacific Northwest Direct Seed Association
For more information, visit www.directseed.org/

The mission of the Pacific Northwest Direct Seed Association (PNDSA) is to bring partners together within WA, OR, and ID to advance direct seeding practices, specifically to "provide information exchange, advocacy on conservation policy issues, and research coordination that supports the adoption of environmentally sustainable and economically viable direct seed cropping systems."

IMPACT

The Pacific Northwest Direct Seed Association brings together producers, researchers, agencies, and industry experts to advance sustainable farming practices in the Pacific Northwest.

The PNDSA's major initiatives include:

1. Providing outreach and training to address direct seed production strategies, soil health, weed and disease management, and the latest research at our annual conference, direct seed breakfasts and field days, and monthly electronic newsletters and the Direct Link hardcopy newsletter.
2. Participating in policy advisory committees with the U.S. Department of Agriculture Natural Resources Conservation Service, Washington State Department of Ecology, U.S. Environmental Protection Agency, and other state and national conservation and agriculture policy groups.
3. Coordinating and supporting research needs for direct seed producers, including relationships with REACCH, Washington State University, University of Idaho, Oregon State University, NRCS, and private agribusinesses.
4. Developing and implementing the Farmed Smart Sustainable Agriculture certification program, which offers farmers a consumer brand to promote their adherence to defined conserva-

Chuck Schmidt, Pacific Northwest Direct Seed Association board member and farmer, seeding into wheat stubble with his Horsch Anderson direct seed drill near Rosalia, WA. Photo by Mortimer Productions.

Direct Seed field day at St. John, WA, to review direct-seed test plots, hosted by the Palouse Rock Lake Conservation District, Cook Agronomy Farm, and the Pacific Northwest Direct Seed Association. Photo by Kay Meyer.

tion standards, certifies that they are using sustainable practices, and develops markets for certified sustainable products.

The PNDSA was formed in 2000 after the Solutions to Environmental and Economic Problems (STEEP) program was complete, yet the need continued for an interdisciplinary research, policy, and support group that would develop profitable cropping systems technologies for controlling cropland soil erosion and protecting environmental quality. The REACCH project further expands and supports these causes by involving scientists, educators, producers, and stakeholders throughout WA, ID, and OR.

Specific areas of collaboration and beneficial aspects between REACCH and PNDSA are as follows:

- Many of the producer stakeholders involved with REACCH studies are direct-seed producers and PNDSA members.
- Research that REACCH is focusing on is very pertinent and directly relates to direct-seed cropping systems, including the effects of conservation management on soil organic matter, nitrogen cycling in crop rotations, precision nitrogen management, cover crops, carbon credits from tilled and no-tilled winter wheat, and earthworm density, to name a few.
- The PNDSA provides additional communication and outreach channels for REACCH to inform direct-seed producers on the results and application of this research to improve their operations.
- The Farmed Smart Sustainable Agriculture certification program will be able to use REACCH's scientific results to further quantify the benefits of direct-seed cropping systems for mitigating climatechange concerns, including reducing carbon and nitrogen emissions, increasing soil organic matter, and creating healthy soil that creates a more reliable cropping system and greater moisture retention.
- PNDSA has invited REACCH committee members to be a part of the PNDSA conference committee to integrate oral and research poster presentations into the 2015 conference with an estimated reach of 600 attendees.
- PNDSA showcases the REACCH farmer-to-farmer case study videos at agricultural trade shows and seminars to promote REACCH projects and highlight the conservation agricultural practices included in the study.

As the REACCH program moves into the final stages of integrating the separate research project and determining overall outcomes and impacts, the PNDSA looks forward to continuing to support REACCH.

Sustainable Agriculture
FARMED
SMART
CERTIFIED
Sustainable Agriculture

Getting climate information to producers

Bea Van Horne (bvhorne@fs.fed.us), Director, Northwest Regional Climate Hub

Farmers and ranchers interested in climate projections today need only look as far as the Internet, which presents a tremendous amount of climate data, graphs, and other resources. But how should they incorporate the data they find into the decisions they make at their own location on a daily, seasonal, or yearly basis? Or, more fundamentally, how do they decide which information is valuable and relevant to assessing alternative crops, timing, tillage, and marketing? In February 2014, the U.S. Department of Agriculture (USDA) established seven regional climate hubs to address this exact need—to help the owners and managers of working lands better access information on the effects of climate change to inform their investment decisions (Figure 1).

IMPACT

Northwest Regional Climate Hub activities will assist in the production of useful tools and applications so producers and educators can incorporate knowledge about climate risk and variability into their daily work. By bringing research and extension scientists and specialists together to develop these tools and information, the hub will increase the likelihood that research information will be used in making decisions affecting farms and landscapes. If producers can make better decisions to deal with an increasingly variable climate, they will be more successful at providing high-quality produce and other agricultural products to the American public at a reasonable cost.

The Northwest Regional Climate Hub (NRCH) covers ID, AK, WA, and OR. It works with partners to develop and deliver useful scientific information about climate risks by improving communication between researchers and extension organizations. To accomplish this, it works closely with extension services to help stakeholders access information specific to their location that addresses the financial and environmental costs and benefits of their decisions. Some of these decisions are informed by short-term seasonal data, while others can incorporate 5-, 10-, or 20-year time frames. As a result, producers on working landscapes will become more successful by incorporating information on climate change into decision making while minimizing their contribution to greenhouse gases.

The mission of the regional hubs is to communicate research information, such as from the National Institute of Food and Agriculture's Coordinated Agricultural Projects (CAPs), Pine Integrated Network: Education, Mitigation, and Adaptation Project (PINEMAP), Sustainable Corn,, and REACCH—which represent substantial investments in research to understand relationships between agriculture and climate change. NRCH works with REACCH scientists to match available information with producer needs.

Bea Van Horne, director of the U.S. Department of Agriculture's Northwest Regional Climate Hub.

NRCH also provides a website (http://climatehubs.oce.usda.gov/) that can be used by outreach and education specialists to access information on adapting to and mitigating climate change. The hub has invested in the development of a tool, AgBiz Logic™, that helps farmers understand the economic and environmental consequences of alternative decisions. This tool will incorporate information on projected climate changes, effects of water and temperature on yield of major crop types, and costs and benefits of "no-till" approaches. The hub has worked with partners in ID, WA, and OR to plan and hold a meeting of climate researchers and extension specialists in the three states to develop a community of interest around common priorities in climate change adaptation and mitigation.

We often hear that extension and education specialists would like to be brought into the design of research projects, rather than handed a completed product that may not be in a format useful for them. NRCH has brought together groups of agricultural researchers and extension specialists to support the development of tools that are truly useful to producers. Producers say they are already supplied with too much data—they would like a simple application that synthesizes these data and describes risks or alternative scenarios for future climate.

In the Pacific Northwest, the major concerns related to climate change are reduced snowpack and resulting winter flooding and summer low flows; a longer dry season; heat stress, especially for livestock; lack of cooling days for fruit crops; erosion from late winter or early spring flooding; and increases in plant and animal diseases. It is also possible that some crops, such as cereals, will

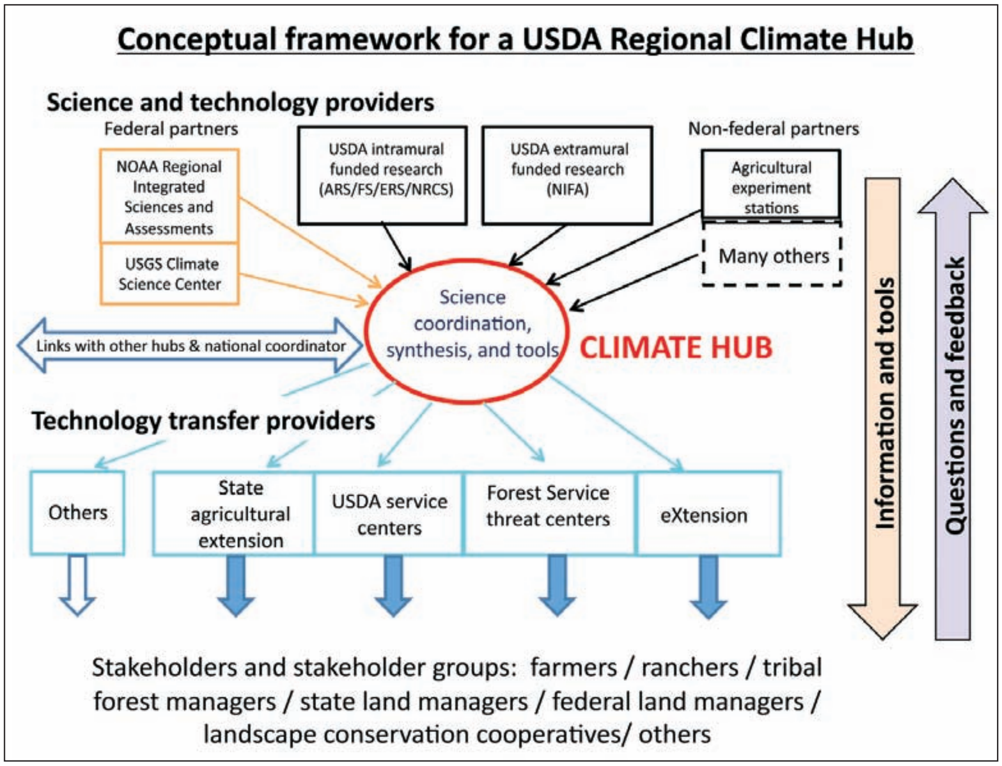


Figure 1. *The U.S. Department of Agriculture's Regional Climate Hubs help landowners and land managers gain access to information on climate change in their region so they can make informed decisions for their farms and landscapes.*

increase in productivity. Commodity prices may rise as other areas of the country experience extreme drought or storms. All of these factors can influence investment decisions, and some of them can be predicted with reasonable certainty, given current and future rates of generation of greenhouse gases. Sustainable agricultural practices, such as building soil organic structure, fertilizing and irrigating at conservative levels, and diversifying crops and livestock, will be relatively successful as climate variability increases over the next several decades and beyond.

Flooding on Paradise Creek upstream of Moscow, ID, during the spring of 2012. Photo by Erin Brooks.

Author index

Bold page numbers indicate primary article by author

Four generations on the Blair farm, Kendrick, ID, founded in 1903. Top left: Reinhard Wilken, grandfather of Robert Blair, the current manager of the farm, plowing with horses in the 1920s. Top right: Cletrac with a bean cultivator in the 1930s. Middle right: Robert Blair's mother, Marga Wilken Blair, on a Farmall M, cultivating beans in the 1950s. Bottom right: Robert Blair on a Case 2470, disking pea ground in the 1970s. Bottom left: Blair's son Dillon harrowing stubble ground with a John Deere 8520T in 2010. Center: Logan Blair with a hexacopter in 2013. Photos courtesy of Robert Blair.

The faces of REACCH

Join a global network developing integrated approaches to address changes in cereal production in semiarid regions.

November 13-14, 2015 • Minneapolis MN, USA

Transitioning Cereal Systems to Adapt to Climate Change

www.aridcereals.org

Our conference will:

- Establish a global network of researchers addressing the effects of climate change on cereal systems in semiarid regions,
- Develop a plan for maintaining the vitality and utility of this network to ensure cross-fertilization and rapid dissemination of effective approaches,
- Establish a protocol for sharing approaches to integrated research, outreach, and policy to improve climate resilience of cereal systems in semiarid regions worldwide,
- Contribute to greater sustainability of cereal production systems in semiarid regions, and to global food security through the 21st century.

Conference held prior to:

Synergy in Science:
Partnering for Solutions
ASA • CSSA • SSSA • ESA
2015 MEETING
Nov. 15-18 | Minneapolis, MN

The REACCH project is sponsoring a special workshop in 2015 to bring together researchers who are working on the challenge of producing cereal crops sustainably as climates change around the world. By sharing approaches and knowledge we can benefit farmers everywhere.

The REACCH project is designed to enhance the sustainability of cereal production systems in the inland Pacific Northwest under ongoing and projected climate change, while contributing to climate change mitigation by reducing emissions of greenhouse gases.

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