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

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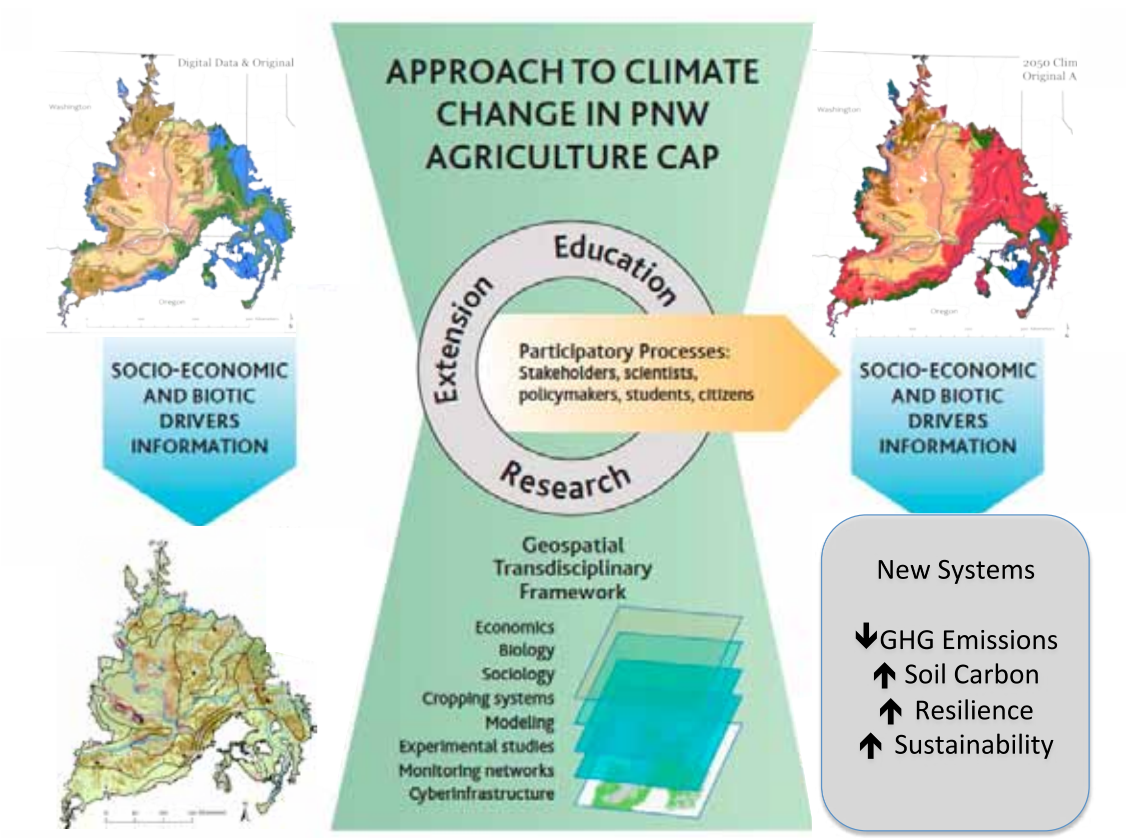
Welcome to REACCH: Project overview

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

Some of the most productive wheat land in the world can be found in the inland Pacific Northwest (IPNW) region, which includes northern Idaho, north central Oregon, and eastern Washington. The tremendous importance of cereal-based agriculture greatly impacts local economies, and influences regional culture and communities. The REACCH project is designed to enhance the sustainability of cereal production systems in the IPNW 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 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 extend this science to stakeholders.

Our third annual report provides a compendium of 41 short reports representative of activity underway across all of our project areas. It is designed to convey the breadth and depth of the project, and to emphasize the immediate or near term impacts this work can have or is having for our region's producers, educators and other stakeholders. The report is also intended to initiate the necessary two-way conversation between scientists, extension educators, producers, teachers and other users of our information. We invite you to follow up with ideas or other responses you may have to these articles through our website (www.reacchpna.org), or by talking with REACCH researchers and students or our stakeholder advisory group members. We are proud of what REACCH is accomplishing and are deeply committed to producing results that will be useful to Pacific Northwest agriculture.



The REACCH project in overview. If the REACCH project could be represented in a single figure, it might look like this. The maps at the top show the climatically determined production zones of the REACCH region in their approximate distribution in 1990 (on the left) and in 2050 (on the right). Warmer summers and wetter winters cause these zones to shift, and create a new zone (in red) that has not existed in our region before. How will wheat production systems need to change to adapt to this shift? The project is using a transdisciplinary approach (involving social and biological sciences, stakeholder involvement, Extension and education) to help this happen in a way that remains profitable, conserves the soil resource, increases resilience, and reduces emissions that can exacerbate climate change.

REACCH goals

Project Goal: Enhance 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 gasses.

Supporting Goals:

- **Adaptation:** Develop and implement sustainable agricultural practices for cereal production within existing and projected agroecological zones throughout the IPNW.
- **Mitigation:** Contribute to climate change mitigation through improved fertilizer, fuel, and pesticide use efficiency, increased sequestration of soil carbon, and reduced greenhouse gas (GHG) emissions consistent with NIFA's 2030 targets.
- **Participation:** Work with producers, stakeholders and policymakers to promote practical, science-based agricultural approaches to climate change adaptation and mitigation.
- **Education:** Increase the number of scientists, educators and extension professionals with the skills and knowledge to address climate change and its interactions with agriculture.

Partners and collaborators

- 4 Institutions
- 3 States
- 25 Project investigators,
- 30 Graduate students and postdocs
- 12 Academic departments at three land-grant universities, and the USDA-ARS.

Scientific Advisory Panel members: Karen Garrett, Kansas State University; 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 NGO's, 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.

REACCH team and stakeholders at WSU Cook Farm

Full Biographies can be found at: https://www.reacchpna.org/about-reacch/

Contact us at: reacchpna@uidaho.edu

The most important and impactful period for the REACCH project is just beginning. This report highlights our transition from project establishment to our next phase: generating and communicating research results useful for our stakeholders in managing risks and opportunities in the context of climate change.

Collaboration with multiple stakeholders with diverse backgrounds, interests and experiences helps us meet the needs of our agricultural communities. We are always interested in hearing your questions, concerns and ideas. Contact us anytime! To get involved or for more information visit: **www.reacchpna.org**

Highlights of impacts, outcomes of REACCH

Goals key for this list:

Adaptation

Mitigation

Education

Participation

- Improved knowledge among producers of historical and projected changes in PNW climate and implications for agriculture (A, M, E, P)
- Improved understanding by scientists and producers of agroecological zone (AEZ) concepts as an indicator of agriculture's responses to climate and other factors that influence cropping system design and management (A,M,P)
- Improved understanding by producers of the effects of AEZ on costs of production, profitability and potential for cropping systems intensification based on regionwide enterprise budget surveys (A,P)
- Improved knowledge of the integration of oilseed crops into wheat production rotations, as a result of education by the Washington Biofuels Cropping Systems (WBCS) and REACCH (A,P)
- Increased regional use of stripper headers due to the Ralston high residue farming project (A,P)
- Increased interest in growing winter legumes in the drier AEZs (A,P)
- Increased grower awareness of specific diseases, pathogens, and insect pests of wheat and their potential responses to climate change (A,P)
- Increased grower awareness of herbicide resistance in downy brome (A,P)
- Increased understanding of agriculture and climate change science among extension and other agricultural professionals who interact locally with producers and land managers, based on post-training evaluations (A,M,P)
- Increased awareness among teacher participants of the role of agriculture and the need for sustainable agricultural systems and better methods to understand and study agricultural sustainability, based on region-wide survey (E)
- Increased skills among these teachers in integrating climate change into classroom lessons concerning environmental factors affecting agroecosystems, resulting from teacher workshops (E)
- Increased capacity of graduate and undergraduate students associated with REACCH to work in transdisciplinary research, education and extension teams (E)

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Integration is the future

Sanford Eigenbrode (sanforde@uidaho.edu) UI

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 these interact. Changes in weather trends and variability (climate change) introduce additional complexity into agricultural systems that are already difficult to manage sustainably. To address this complexity, our research, extension, and education efforts also must be deeply integrated and consider multiple aspects of production systems. This is a key premise of REACCH.

An integrated framework: The REACCH project considers wheat production systems holistically. Our conceptual model (Figure 1), prepared with input from all project participants, summarizes the project conditions, resources, approach, outputs, and intended impacts. All project members integrate their research, extension, and education efforts within this conceptual model, while addressing REACCH's four goals: (1) adaptation, (2) mitigation, (3) participation, and (4) education. Each goal requires specialized effort to achieve appropriate integration, and our activities may cut across multiple goals or have disciplinary integration within a single goal. We have numerous structures and activities to enable this integration.

IMPACT

Changing climates will affect all components of Pacific Northwest agricultural production systems, including technology, management practices, biological, economic, and social aspects. Achieving adaptation to changing climate and mitigation of activities that can affect climate and benefit producers will require coordinated efforts in research, education, and extension. To achieve its goals, REACCH is organized to allow unprecedented integration among the three missions of the land grant universities and Agricultural Research Service and among all the relevant disciplines.

Integration across teams: Integration across teams is required because specific research areas support and enhance research and information development within other areas. For example, climate scientists are providing downscaled historical and project climate data to researchers across the project to generate projections for cropping systems performance; pest, weed, and disease pressures; and greenhouse gas emissions. Integration between social and biophysical scientists is also ongoing. Two regional producer surveys designed by REACCH sociologists with input from all project teams are now guiding research and extension activities across the project. REACCH economists are directing a project-wide effort to develop future scenarios (Representative Agricultural Pathways) that consider technological, economic, and policy factors that could affect Pacific Northwest agriculture over the coming decades.

Integrating teams: Our entire team meets often to discuss specific integrating activities (e.g., interpretation of a long-term longitudinal producer's survey or development of the conceptual model) and other issues pertaining to the project. However, several specific working teams focus explicitly on integration. The Agroecological Zone (AEZ) group is using new tools and data analysis methods to characterize the production zones of our region, both in terms of the climatic factors that influence production, and the production practices being employed on the ground. This approach provides insights into the diversity of production practices and guides research by all of our participating teams. One of our teams is focused on uniquely coupled integration of climate, cropping systems and economic modeling platforms to generate projections of yields and economic consequences of different future scenarios in our region.

Extension: Extension efforts are coordinated by an extension team, but require collaboration with all REACCH scientists, students, and stakeholders. Together, extension, social, and economic scientists have learned that farmers want more information about sustainable nitrogen management and alternative crops, and they are developing a series of webinars and interactive digital resources with the cyberinfrastructure team to meet these and other needs regarding agriculture and climate change. Collaborative efforts can be enhanced through mini-grants, which are available for people interested in developing extension materials, including students and non-university employees. Mini-grant projects target stakeholder needs but often include stakeholders in project development as well. REACCH is committed to providing meaningful interactions with producers and other stakeholders and always encourages two-way communication and input from them. Based on feedback from stakeholders, news from the project appears quarterly in the OutREACCH newsletter.

Education: Our graduate students and undergraduate interns are trained in aspects of integration across the REACCH project. Graduate students work in interdisciplinary teams and are involved in creatively communicating project information through extension products and materials for teachers. Summer undergraduate researchers, joining us from around the country, are exposed to cross-disciplinary science across REACCH to promote interdisciplinary collaborations. REACCH assists regional K–12 teachers in incorporating agriculture and climate change science into their curriculums.

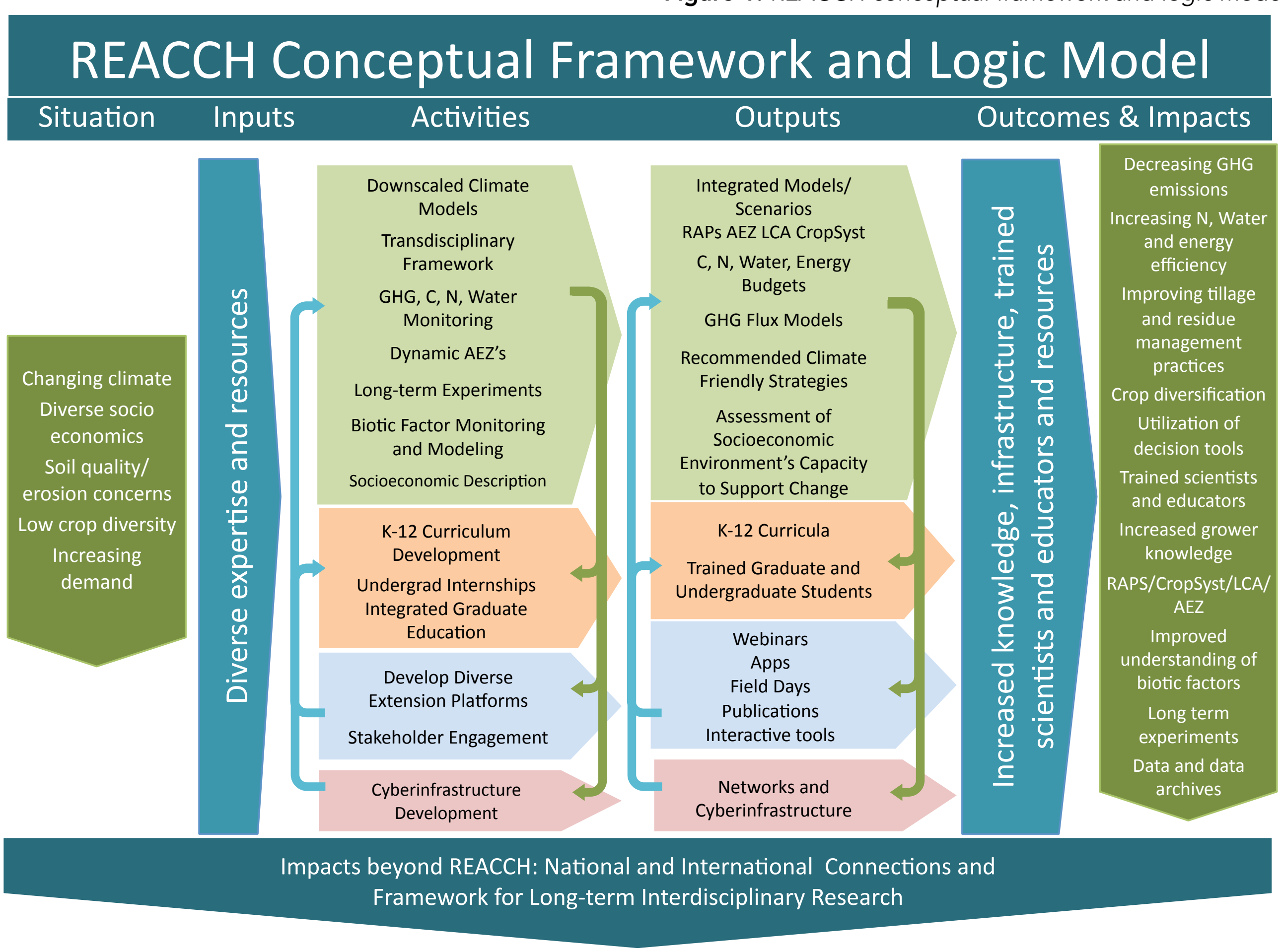
Data management: Integration among multiple disciplines requires efficient methods for data storage. REACCH data are being assembled into a single repository, constructed to accommodate multiple data types, from social to biological and from single experiments to large regional-scale modeling outputs. All the data are tagged systematically to facilitate retrieval, manipulation, and visualization by REACCH researchers. These tools will allow our project members and future collaborators to access, explore, and synthesize all REACCH data.

Combine unloading in bankout wagon during harvest on a farm east of Genesee, Idaho. Photo by Hilary Donlon.

Assessment: To help us maintain strong, positive interactions and collaborations, primary investigator David Meyer (Boise State University) conducts an annual survey to assess participant engagement, understanding of project activities, and satisfaction with communication and leadership. He is also conducting social network analysis to delineate the collaborative architecture of our whole team. So, not only is our assessment activity tracking our project milestones and deliverables, it is also assessing the strength of our collaborative process.

Our project's integration is broader and more thorough than has been the norm for publicly supported research, extension, and education projects. Because of this integration, we are better prepared to address realistic challenges for sustaining the productivity and profitability of agriculture. This requires our faculty, staff, and students to adopt a new way of thinking about their efforts, as part of a large and coordinated endeavor, and we are embracing this philosophy together. Our integration parallels the integration required for successful farming, and it develops an approach that will characterize future research, extension, and education intended to help sustain complex systems that are important for human well-being.

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



Defining agroecological classes for assessing land use dynamics

Dave Huggins (David.Huggins@ARS.USDA.gov) USDA-ARS, Rick Rupp WSU, Harsimran Kaur WSU and Sanford Eigenbrode UI

Land use is a dynamic property that arises from multiple socioeconomic and biophysical factors and is highly relevant to climate change science and agricultural sustainability. For agroecosystems, changes in socioeconomic factors (e.g., emerging markets, increasing fertilizer prices, or advances in precision technologies) as well as biophysical variables (e.g., weather and climate variations or land resource degradation) are powerful signals to land managers, expressed through the continuous evolution of technologies, management practices, and agroecosystem properties. Not surprisingly, land use classification has been increasingly used for structuring and implementing agroecosystem management strategies and as a basis for organizing and interpreting agroecological data for inventory, monitoring, research, education, and outreach.

IMPACT

Defining agroecological classes (AECs) enables researchers, stakeholders, students, the public, and policymakers to acquire a more holistic understanding of agriculture and climate change. AECs are intended to be part of a prescription for land management that, given climate change, will support and enhance the use of information from climate models; socio-economic models; crop models; pest, disease, and weed vulnerabilities; and many other data sources.

Agroecological zones (AEZs) attempt to delineate land use into relatively homogeneous areas where constraints and capabilities result in common production systems. These and other land use classifications have primarily relied on methods that integrate multiple geospatial layers of relatively stable biophysical drivers such as climate, physiography, geology, soil, and native vegetation. Here, "weight of evidence" and expert opinion regarding identification and integration of agriculturally relevant biophysical drivers have led to the development of agroclimatic zones, Ecoregions, and Major Land Use Areas.

Defining AEZs based on relatively stable biophysical drivers provides a consistent standard for assessing factors such as agroecosystem health and land resource suitability. Weak relationships, however, can occur between delineated zones and actual land use. This arises as agroecosystem complexity and dynamics are substantially augmented by socioeconomic drivers that promote greater transfers of materials, energy, and information

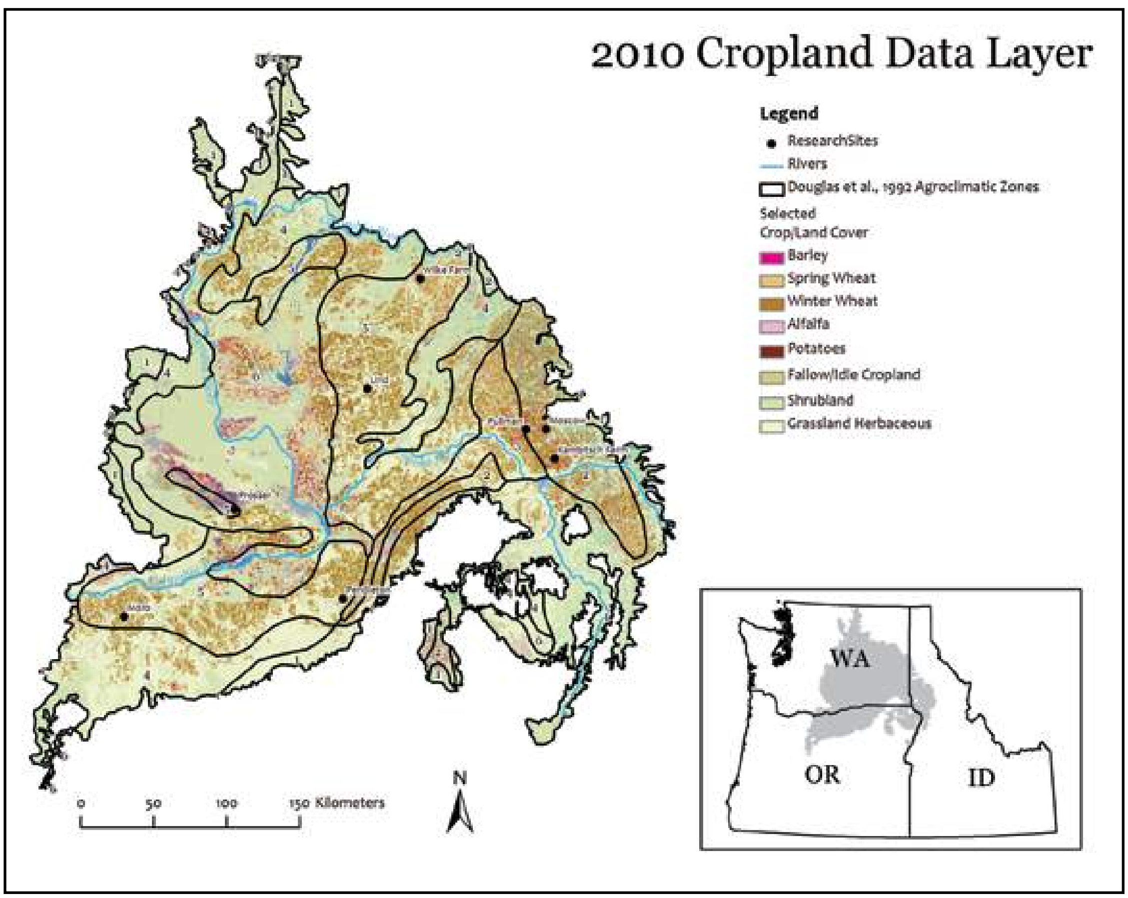


Figure 1. *Land use classification of the REACCH study area from National Agricultural Statistics Service (2010).*

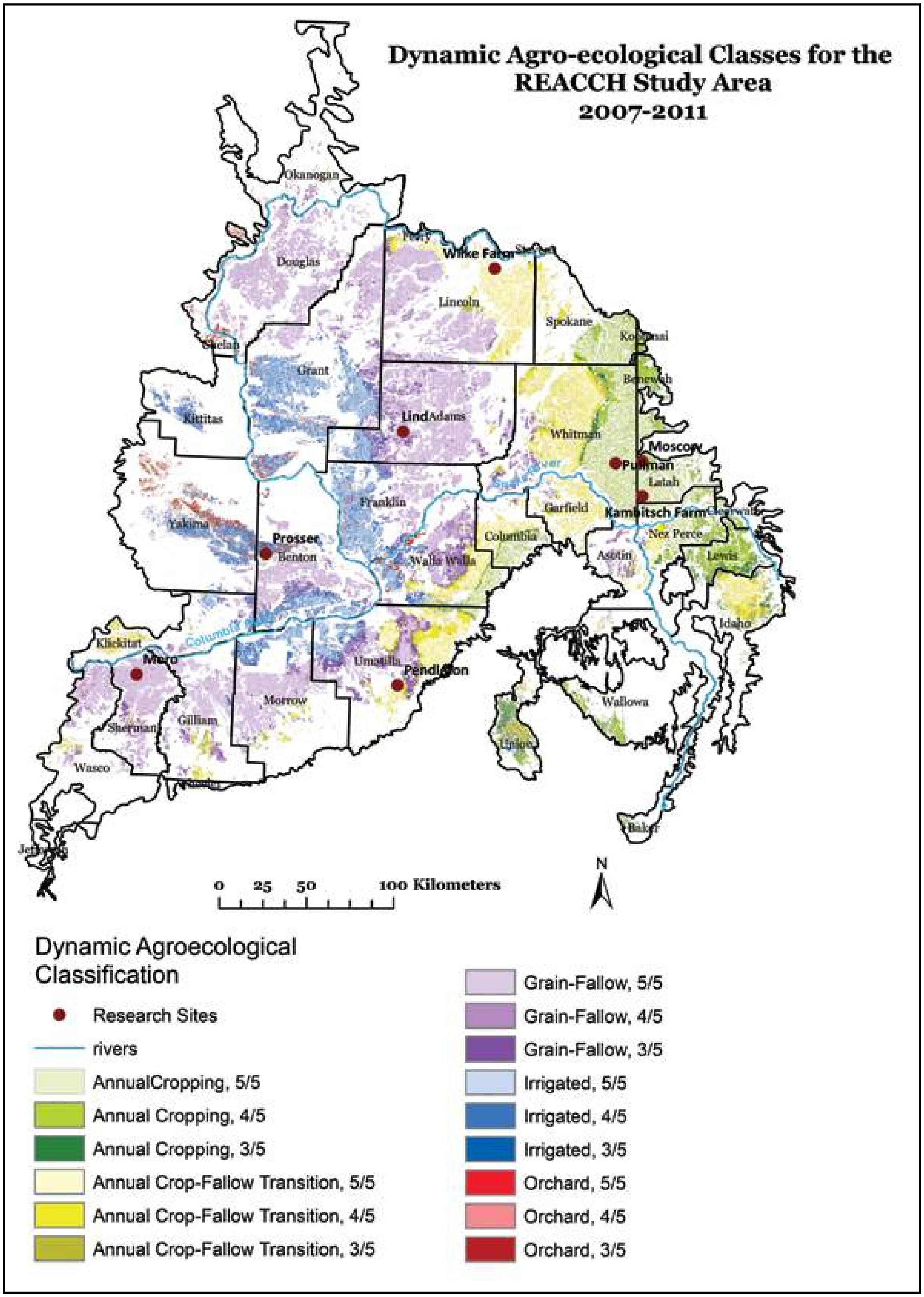


Figure 2. *Agroecological classification (AEC) for REACCH study region, where cells (56 m) had the same AEC for 3, 4 and 5 years during the 5-year period (2007–2011). Research sites on this map are locations of long-term experiments being conducted as part of REACCH.*

among interconnected systems than are found in natural ecosystems. Integration of socioeconomic drivers into AEZs, however, has been elusive, as relevant geospatial data are often lacking.

New approaches to land classification are becoming possible as geospatial capacities to identify land use and associated biophysical and socioeconomic drivers increase. In contrast to delineating areas derived from simplifications of biophysical and socio-economic drivers, classification based on land uses that have emerged as a consequence of these determinants may be advantageous. Here, no assumptions would be made regarding the magnitude and interactive effects of various agroecosystem drivers on shaping land use. Each classified area of agricultural land use would be considered a discrete system that emerged from the interactions of many diverse factors over time. Agroecological

A farmer gazes across his wheat field in Eastern Idaho. Photo courtesy Stone-Buhr Flour Company.

areas could then be derived solely from classifying the geographic distribution of defined agricultural systems (e.g., grain-fallow). Defining agroecological classes (AECs) in this way deviates from the current concept of AEZs and enables potentials to: (1) apply AEC classification at fine geographic scales; (2) provide baseline information that spatially classifies current AECs and therefore the capacity to detect spatial changes over time; (3) formulate hypotheses and analyze relationships among biophysical (e.g., climate, soils, terrain) and socioeconomic (e.g., land prices, commodities grown) factors useful for understanding AEC distribution and for predicting changes; (4) develop AEC-relevant research, education, and outreach strategies for climate mitigation and adaptation as well as other sustainable agricultural practices; and (5) integrate biophysical and socioeconomic data sources to pursue a transdisciplinary examination of AEC futures including considerations of climate change and agricultural sustainability.

Specifically, our objectives are to: (1) develop methodology to classify agricultural land representing major AECs of the inland Pacific Northwest based on single years of National Agricultural Statistical Service (NASS) cropland data and specific defining criteria; (2) characterize defined AECs with respect to climatic and edaphic drivers; (3) initiate monitoring and assessment of spatio-temporal changes in AECs; (4) compare AECs with currently used land classifications that are based on biophysical drivers; (5) provide a spatio-temporal context for assessing agricultural sustainability, including the forecasting of climate change effects on AECs as well as targeting of research, education, and outreach efforts to effectively study, plan, and implement mitigation and adaptation strategies.

The Cropland Data Layer (CDL) from NASS provides annual land classification of specific crops grown or not grown (e.g., winter wheat, barley, fallow) at a fine resolution (30- or 56-m scales) (Figure 1). For a given year, these data do not directly identify crop sequences that would occur on an agricultural field over time. Therefore, we developed a methodology that allows a single year of NASS cropland data to be used with specific criteria to define three dryland farming AECs: (1) grain-fallow, >40% fallow; (2) annual crop-fallow transition, 10 to 40% fallow; and (3) annual cropping, <10% fallow. In addition, an irrigated AEC was defined as an annual cropping region (<10% fallow) where mean annual precipitation was less than 330 mm or where crops known to require irrigation were grown. Non-agricultural land use/cover were also identified using Anderson's classification (e.g., range, forest, urban, water). Applying the methodology each year enables the capacity to detect spatial changes in AECs and other land uses over time, although it should be recognized that classification errors of the CDL also contribute to this dynamic (Table 1).

Range is the largest and most stable land use in the REACCH study region, with nearly 90% remaining unchanged during 2007 through 2011. Dryland AECs were also relatively stable, with the primary alternative a land use strategy that involved more fallow or a complete shift out of crops (e.g., range). Agricultural land use dynamics are spatially identified in Figure 2, where transitional areas among various AECs are emerging after 5 years. Changes in crops grown within each AEC can also be quantified over time (Table 2). These data will be useful for tracking temporal trends in the extent of various crops.

Table 1. *Land use for REACCH study region, area remaining unchanged and primary alternative land use (2007-2011).*

Land use/cover classification	Total area mean (ha)	Total area CV[1] (%)	Area unchanged (%)	Alternative land use (%)	Alternative land use (%)	Alternative land use (%)
Range	5,318,154	3.3	88.9	Grain-Fallow (2.4)	Urban (2.0)	Forest (1.9)
Forest	477,392	2.7	73.6	Range (22.6)	Urban (1.3)	Water, other (1.0)
Urban	365,774	14.2	45.3	Range (28.7)	Grain-Fallow (8.1)	Irrigated (5.2)
Annual Cropping	541,011	14.8	80.9	A-C-transition (12.1)	Range (8.6)	Urban (2.1)
Annual crop-fallow transition	675,608	17.1	69.1	Grain-Fallow (11.8)	Range (9.0)	Annual Cropping (2.5)
Grain-fallow	1,249,928	8.5	81.0	Range (7.8)	A-C transition (5.1)	Irrigated (3.2)
Irrigated	459,009	8.8	68.3	Range (12.8)	Grain-Fallow (10.0)	Urban (3.0)
Orchard	79,669	82.1	29.7	Range (29.2)	Urban (9.6)	Irrigated (9.3)
Water and other	211,733	11.0	72.7	Range (15.8)	Orchards (4.0)	Irrigated (2.5)

[1] *Coefficient of variation*

Table 2. *Crops and fallow by agroecological class (AEC) for the REACCH study region (2007-2011).*

Agroecological classification AEC	Year	Total area (ha)	Winter wheat (%)	Spring wheat (%)	Spring barley (%)	Spring lentil (%)	Spring pea (%)	Spring garbanzo bean (%)	Canola (%)	Fallow (%)	Alfalfa (%)	Potato (%)
Annual Cropping	2007	553,084	48.9	13.6	10.1	6.6	4.4	5.2	0.6	3.0	2.9	0.0
	2008	611,095	45.0	14.8	7.9	5.2	6.0	3.6	0.6	3.0	8.8	0.0
	2009	592,771	38.4	17.6	3.0	7.4	6.2	3.8	0.3	3.3	2.0	0.0
	2010	540,636	41.3	17.7	2.9	9.1	5.8	6.9	0.6	3.2	5.0	0.0
	2011	407,468	41.7	18.5	3.7	6.1	4.7	8.3	0.4	4.7	4.5	0.0
Annual crop-fallow transition	2007	552,686	46.0	14.0	7.4	0.2	1.7	0.3	0.3	27.5	2.3	0.0
	2008	643,819	42.7	15.2	6.2	0.1	1.7	0.2	0.3	27.5	5.1	0.0
	2009	674,744	41.6	18.4	2.3	0.3	2.1	0.2	0.2	26.9	3.4	0.0
	2010	640,817	40.4	18.6	2.4	0.5	1.9	0.5	0.2	27.6	5.5	0.0
	2011	865,972	41.9	16.0	3.3	0.8	1.3	0.8	0.5	25.8	5.3	0.0
Grain-fallow	2007	1073,443	46.4	4.5	0.8	0.0	0.7	0.4	0.1	43.8	2.3	0.0
	2008	1,290,512	44.0	7.2	0.6	0.0	0.7	0.3	0.1	42.6	2.5	0.0
	2009	1,235,417	45.8	4.9	0.3	0.0	0.8	0.4	0.1	43.8	1.9	0.0
	2010	1,345,175	44.7	4.2	0.3	0.0	0.6	0.5	0.1	44.4	3.2	0.0
	2011	1,305,093	45.6	5.8	0.5	0.0	0.6	0.5	0.2	43.0	2.5	0.0
Irrigated	2007	406,036	8.3	4.1	0.1	0.0	1.3	1.7	0.2	0.7	29.6	18.0
	2008	477,522	9.5	7.5	0.1	0.0	1.7	1.7	0.1	1.2	19.0	14.1
	2009	432,006	8.3	5.2	0.1	0.0	2.8	3.1	0.2	1.0	22.6	15.0
	2010	466,851	6.0	4.3	0.1	0.0	1.9	2.8	0.1	1.2	20.7	14.7
	2011	508,785	6.9	7.5	0.1	0.0	1.6	1.7	0.2	1.2	15.5	14.8

Photo courtesy Stone-Buhr Flour Company.

Climate change and agriculture: What do stakeholders need?

Georgine Yorgey (yorgey@wsu.edu) WSU, Leigh Bernacchi UI, Chad Kruger WSU, J.D. Wulfhorst UI, Sylvia Kantor WSU, and Kristy Borrelli UI

In order to ensure that REACCH effectively addresses perceived stakeholder concerns about climate change and agriculture, we engaged with a variety of individuals and groups concerned with this topic.

- Dryland and irrigated producers with more than 50 acres in wheat were surveyed by mail in winter of 2012–2013. Additional in-depth interviews are being conducted with a subset of producers who are experimenting with new technologies or management practices.
- Crop advisors, farmer associations, individuals working at government agencies, and environmental groups were interviewed.
- Members of the project's stakeholder advisory committee were surveyed and continue to provide input in an advisory capacity. This group includes industry representatives and teachers, in addition to the groups mentioned above.

These activities have enhanced our understanding of stakeholders' opinions and needs around the topic of agriculture and climate change in the inland Pacific Northwest. Key findings are described below and summarized at the conclusion.

IMPACT

Our stakeholder engagement activities suggest that REACCH can serve stakeholders' needs by focusing on mitigation activities that offer co-benefits and on production practices that may serve as a buffer against the effects of a changing climate. The project can also provide information to help producers evaluate the amount of risk that various aspects of future climate change present and understand the implications for their farming operations, especially with regard to water supply, economic risks, and risks regarding regulation.

Attitudes and beliefs: The majority of surveyed producers have observed weather changes in their lifetime (80%). However, they were less likely to agree that climate change is human-caused (Figure 1). During interviews, individuals in farmer associations and government agencies suggested that these mixed attitudes have led to producers being generally more interested in strategies that could help them adapt to climate change than in activities that might mitigate climate change. Interest in mitigation arose mainly when such activities provided other co-benefits. For example, although improved residue management can provide climate benefits by storing carbon in the soil as organic matter, producers were mainly interested in the soil quality and soil water storage improvements it provides.

Surveyed producers were generally uncertain about the risks that climate change poses. When asked how great or small a risk is posed to their farming operations by less reliable precipitation, long-term drought, cost of inputs, climate change policies, or unstable crop prices, many (30–70%, depending on the specific risk) said they did not know (Figure 2). Meanwhile, a smaller but still sizeable group (20–40%) said these factors represented a high level of risk. During interviews, individuals from farmer associations and agricultural government agencies reiterated significant concern about precipitation and water availability. They also discussed uncertainty about the direct and indirect impacts of possible climate-related regulation on the agricultural sector.

Surveyed farmers indicated less concern about two other risks: fewer days with frozen soil and increased intensity of precipitation. The largest group (35–40%) thought these factors represented a moderate level of risk to their operations. An additional 20–35% suggested they were a high risk, while very few (0–10%) said they did not know.

Adapting to climate change: If faced with warming temperatures, reductions in summer precipitation, and increases in winter precipitation by 2050–2080, survey results indicated that the majority of producers (more than 75%) did not think they would need to make more than small changes to their farming operations (Figure 3). Additional analysis (not shown here) suggests that producers who use conservation tillage are particularly likely to think that they will not need to make big changes to their tillage practices. It is possible that producers feel that conservation tillage improves soil quality in ways that can serve as a buffer against the impacts of climate change, in the form of more organic matter and better water-holding capacity. Planned future work will analyze the distribution of responses across agroecological zones in the region and seek to better understand why producers feel that big changes are not necessary.

Research interests: Diverse groups of stakeholders identified specific areas of research they thought would be useful in adapting to or mitigating climate change. Topics that were mentioned frequently, by several types of stakeholders, included:

- **Crop varieties**, including heat- and drought-tolerant varieties and those well suited for no till
- **Water quantity**, including water supply and demand in irrigated and dryland systems, efficiency, and conservation
- **Agricultural practices,** including precision agriculture, alternative crops, cover crops, and residue management
- **Nutrient management**, including changing nutrient needs, nutrient recovery from wastes, and protocols for crediting nutrient management improvements
- **Soil carbon**, including methods for increasing, measurement, and potential benefit for adaptation to climate change

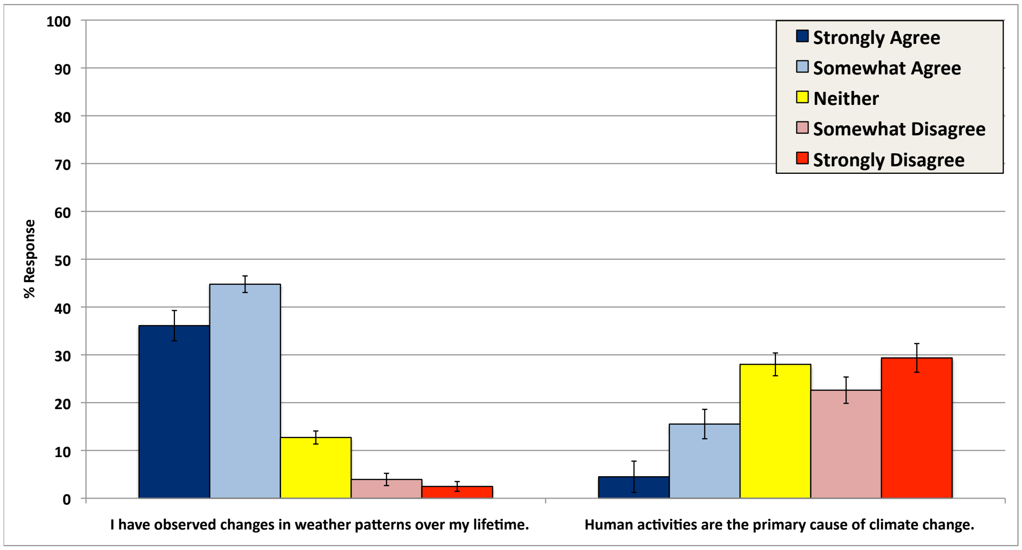


Figure 1. *Most respondents have observed weather pattern changes over their lifetimes, but were less likely to agree that humans are the primary cause of these changes.*

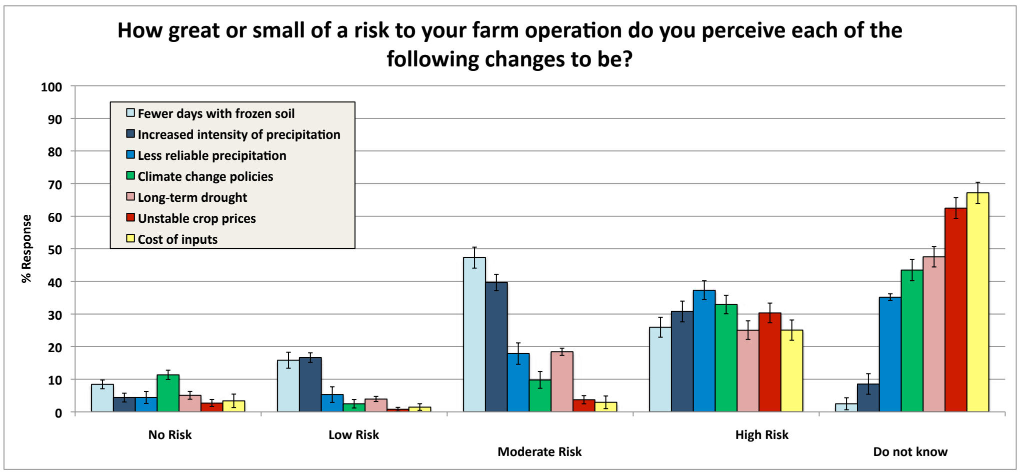


Figure 2. *Many respondents are aware of the moderate to high risks of climatic changes, especially with respect to temperature and precipitation. Most producers are uncertain as to the effects of policy changes and economic impacts.*

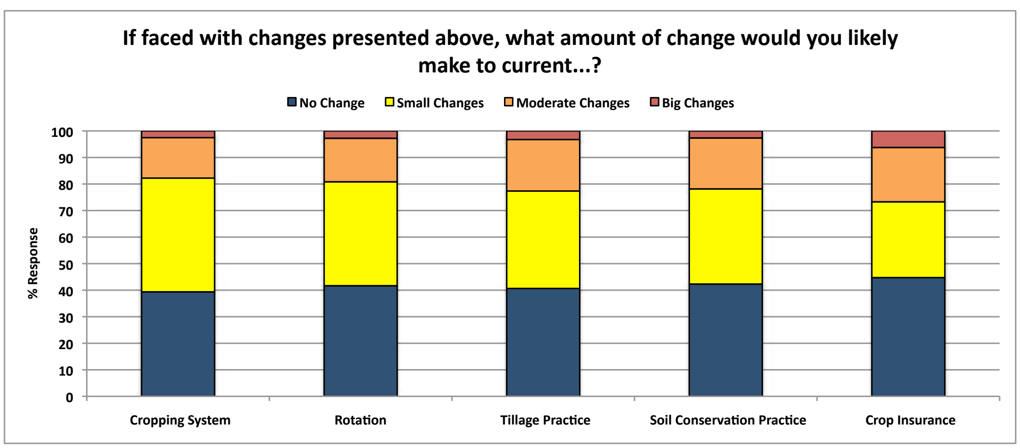


Figure 3. *Most respondents do not anticipate a need for more than small changes to their farming operations in response to climate change. While producers are least likely to make changes to their cropping system and rotation, they are more likely to respond to potential climate changes through modified tillage practices and crop insurance.*

Where to from here? Stakeholders have suggested several ways in which REACCH can serve their needs. REACCH should identify and emphasize mitigation activities that offer co-benefits. For adaptation, REACCH should continue to develop, support and promote production practices that may serve as a buffer against the effects of a changing climate. The project should also provide information to help producers evaluate the amount of risk that different aspects of future climate change present and understand the implications for their farming operations, especially with regard to water supply, economic risks, and risks regarding regulation. When available evidence suggests that risks are significant, efforts should seek to identify strategies that could reduce risk. Finally, REACCH should prioritize the dissemination of information about the specific research topics identified by stakeholders. Some of this information is available through existing research, or will be available from ongoing work that is part of REACCH. Other concerns may need to be addressed in future research.

Developing resources for farmers, with farmers

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As REACCH helps prepare farmers to manage uncertain future conditions associated with climate change, we rely on their experiences to direct us. Farming systems and the impact of disturbances on them are not uniform, and neither are the management decisions necessary to make improvements. Yet, farmers are accustomed to creatively modifying their practices in response to unforeseen opportunities or risks.

Farmer-to-farmer learning is a well-documented strategy for enhancing information sharing that encourages adoption of better practices, and it is important to facilitate interactions among farmers and other stakeholders. Collaboration with farmers and their associates drives development of multiple extension-based projects in REACCH that inform them about agriculture and climate change (Figures 1–3). Three examples of specific farmer-focused REACCH projects currently underway include: (1) surveys, (2) a decision tool for climate change communication, and (3) case studies. Each project involves stakeholders in different ways, but all depend on their expertise and experiences to generate resources that can positively influence production decisions of many producers in the region.

IMPACT

Directly involving farmers in extension product development acknowledges the significance of their experience, understanding, and concerns regarding wheat production systems. Tailoring resources to address producer-defined needs and preferred information sources increases the likelihood that practices that aid in climate change adaptation and mitigation will be adopted.

Producer surveys: Two producer surveys were initiated in the first 3 years of REACCH. A longitudinal survey provides annual updates on the economic and environmental impacts of several conservation farming approaches used by wheat farmers, many of whom are noteworthy for experimenting with a new technology or innovative management in the region. A producer survey develops a picture of the farmer population throughout the region based on their current production practices and perceptions of climate change. Although the survey results may not be used directly by farmers, they help scientists, industry, and other service providers to be better informed and directed to meet farmers' highest priority needs. When farmers candidly share opinions and information about their experiences in a confidential environment, they provide insights about their common concerns, barriers, and preferences. For example, by understanding economic inputs and outputs in various wheat-based farming systems we can help farmers proactively address future economic risks by creating tools to help them make profitable choices for their farm. Similarly, if we know that less reliable future precipitation is a concern for farmers, we can provide information about ways to reduce the associated risks by using improved irrigation practices, drought-tolerant wheat cultivars, or practices that improve soil moisture retention.

Decision tool for climate change communication: REACCH researchers are interviewing certified crop advisors (CCAs) and allied industry representatives to incorporate information from the producer survey they identified as important into a digital decision-support tool that assists with communication about climate change, and adaptation and mitigation practices. Farmers rely on CCAs and industry representatives to provide trustworthy and reliable support for farm management. It is therefore necessary for them to have access to current data and decision support in order to facilitate communication for identifying and choosing options for best practices. With their coopera-

Figure 1. *Farmers interacting with researchers at the REACCH Field Day—Cook Farm, Pullman, Washington. Photo by Sylvia Kantor.*

Figure 2. *A farmer shares his experiences with growing alternative crops in Colfax, Washington. Photo by Dennis Roe.*

tion, REACCH can provide them with a tool that allows them to access and organize complex information rapidly from many locations. For example, CCAs recognize the tension between increased reliance upon technology and loss of cultural management strategies. Knowing the degree to which a subpopulation of farmers relies on precision agriculture or other technologies can inform the way they communicate about adaptation to climate change—without breaking the bank or entirely changing the way they farm. Additionally, since findings from the REACCH producer survey are being incorporated into interview discussions, CCAs and industry representatives are able to gain a better understanding of the farmer constituency in their region.

Case studies: Several grower case studies are being developed by REACCH as digital documents that include short video pieces. The goal is to highlight farmers' conscientious efforts to improve their current farming strategies—strategies that may also allow them to adapt to a changing climate. The case studies focus on a variety of practices with specific environmental and economic benefits in four agroecological zones (AEZs), including: (1) variable-rate nitrogen application in the high rainfall zone; (2) intensive and alternative crop rotation in the intermediate rainfall zone; (3) flex cropping in the low rainfall zone; and (4) diverse crops, intensive rotation, and cover cropping in the irrigated zone. Each one examines how farmers make decisions and manage risk and offers suggestions about the challenges and benefits that farmers have experienced when implementing these practices. As research has shown, farmers are more likely to trust the knowledge and experience of their peers. Thus, case studies can improve the appreciation and unconventional but innovative farming practices and lead to their adoption. Observing conservation practices that are successfully used throughout the region allows farmers to evaluate options for improving practices on their own farm. Exposure to multiple examples encourages farmers to experiment and tailor approaches best suited for their needs and location.

Products from the three projects identified in this report are expected this coming year. Involving farmers and their associated stakeholders in needs assessments and resource development is crucial for creating effective education materials and decision support. In the face of new challenges, it is necessary to learn from past experiences. Farmers have tremendous creativity and experience when dealing with risks, and REACCH will continue to collaborate with them in meeting future challenges and opportunities.

Figure 3. *A REACCH graduate student discusses flex cropping with a grower in Ione, Oregon. Photo by Sylvia Kantor.*

REACCH long-term research sites

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

Wheat is the main crop throughout most of the inland Pacific Northwest, but environmental, economic, and social drivers can alter suitability of wheat varieties, crop rotations, markets, and management practices from location to location. The effects of climate change on wheat production are still uncertain, but are likely to further impact these drivers. To better understand cropping system dynamics throughout the region, nine long-term research farms and partner institutions have been established in different agroecological zones (AEZs) within northern Idaho, north central Oregon, and eastern Washington. Regional-scale research allows scientists to address the diversity among wheat production systems and to identify unique concerns for specific systems. Research sites and the major focus areas for projects at each are summarized below.

Kambitsch Farm, Moscow, Idaho: Trials were established in 1999 to examine conservation tillage and residue management effects on soil properties and crop growth in the annual cropping AEZ. Photo by Brad Bull.

Cook Agronomy Farm, Pullman, Washington: Trials were established in 1999 to focus on site-specific nitrogen management, crop intensification and diversification, residue management, and modeling biophysical processes and economic performance in no-till wheat-based systems in the annual cropping AEZ. Officially designated by the U.S. Department of Agriculture as a Long-Term Agricultural Research Site (LTAR). Photo courtesy of Washington State University.

Columbia Basin Agricultural Research Center, Moro, Oregon: Trials were established in 2003 to focus on low rainfall transition from Conservation Reserve Program (CRP) to crop production, focusing on fertility, fall and spring plantings, and wireworm control. Additional long-term experiments at this site focus on direct-seed, residue management, and crop intensification and diversification in the grain-fallow AEZ. Photo by Stephen Machado.

IMPACT

Long-term agricultural research sites can provide a historical account of environmental quality aspects and farm management practices over several decades. Detailed records and archives can help us understand agriculture's past and ensure the viability of the region's cereal-based agriculture into the future.

Palouse Conservation Field Station, Pullman, Washington: Trials were established in 2001 to focus on crop rotation, rotational nitrogen cycling and management, variable nitrogen rate application, and crop diversification and intensification in a no-till wheat-based system in the annual cropping AEZ. Photo from Google Earth.

Wilke Farm, Davenport, Washington: Trials were established in 1998 to focus on crop intensification and diversification, site-specific nitrogen management, and flex cropping in a direct-seed, no-till fallow system in the annual crop-fallow transition AEZ. Farm-scale plots have been added in 2004 to make research practices more realistic. Photo by Aaron Esser.

Columbia Basin Agricultural Research Center, Pendleton, Oregon: Trials were established beginning in 1931 to focus on tillage and residue management, variety development, nitrogen fertility, recycled carbon and nitrogen, crop intensification and diversification, soil ecology, and pathogens in the annual crop-fallow transition AEZ. Oldest replicated research experiments in the western United States for residue management, tillage, and fertility. Photo by Stephen Machado.

Jirava Farm, Ritzville, Washington: Trials were established in 1997 and focus on long-term alternative cropping systems, conservation tillage, Rhizoctonia control, and residue management in the grain-fallow AEZ, with the goal of reducing fallow by using intensive cropping. Photo courtesy of Washington State University.

Hennings Farm, Ralston, Washington: Trials were established in 1995 and focus on replacing wheat-fallow systems with no-till winter triticale, spring crops, and high-residue farming for soil moisture conservation, weed control, plant pathology, agronomy, and economics for diverse crops and rotations in the grain-fallow AEZ. Photo by Dennis Roe.

Irrigated Agriculture Research and Extension Center, Prosser, Washington: Trials were established in 2011 as a new experiment to investigate winter cover crop and no-till management effects on crop productivity, water and nitrogen use efficiencies, erosion control, and greenhouse gas emissions in the irrigated AEZ. Photo courtesy of Washington State University.

Win-win scenarios for farm and climate

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Given the increasingly large number of management choices facing farmers, choosing practices with the intent of adapting to and mitigating climate change can seem overwhelming. Fortunately, efforts to achieve adaptation and mitigation in regional cropping systems are coupled and can present potential immediate and long-term "win-win" scenarios for both agriculture and climate.

For example, farming practices that improve nitrogen use efficiency can reduce growers' nitrogen fertilizer input costs, while also reducing nitrous oxide (N_2O) and other greenhouse gas emissions. Similarly, reducing periods of fallow can potentially increase farm productivity and income, while production of crop biomass can sequester atmospheric carbon dioxide (CO_2) through the process of photosynthesis. Another example is the incorporation of oilseed crops in many cropping rotations (Figure 1). Further examples of potential short and long-term win-win scenarios are detailed in Table 1.

IMPACT

Many farm management practices can directly benefit farmers by reducing farm costs or improving crop yield and product quality. These same practices are some of the best for adapting and mitigating farms against the effects of climate change.

REACCH continues to identify similar opportunities and help farmers and industry realize them. Coordinated efforts directed at refining and implementing best management practices related to cropping system management tools include: identifying management impacts on carbon and nitrogen flows and greenhouse gas emissions, identifying short and long-term benefits of shifting carbon and nitrogen flows through cropping systems, and improving cropping system flexibility for adapting to climate change. By directing efforts toward addressing immediate concerns, farmers, scientists, and other service providers can be better prepared to address future challenges and engage in opportunities.

Figure 1. *Oilseed crops offer many benefits to farmers and the environment. Canola and wheat grow side by side at Wilke Farm in Davenport, Washington. Photo by Sylvia Kantor.*

Table 1. *Agricultural management practices can offer multiple short- and long-term benefits to farmers 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 the 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 due to canola's strong taproot • Glyphosate-resistant canola is the 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	• Improved resource efficiency and lower loss, as crops are better suited to environment • More tolerant varieties are more adaptable to climate change
Prescription nitrogen 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 by-products	• Increased SOM and improved soil quality • Reduced N fertilizer costs • Recycled valuable nutrients • Reduced landfilling of 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: AEZ = Agroecological zone; BNF = Biological nitrogen fixation; C = Carbon; CO_2 = Carbon dioxide; GHG = Greenhouse gas; N = Nitrogen; N_2O = Nitrous oxide; PNW = Pacific Northwest; PS = Photosynthesis; RR = Roundup-ready; SOM = Soil organic matter

Conservation management effects on soil organic matter

Dave Huggins (David.Huggins@ARS.USDA.gov) USDA-ARS and Tabitha Brown WSU

Soil carbon (C) sequestration is a major agriculturally based strategy for mitigating rising atmospheric concentrations of greenhouse gases. Soil organic carbon (SOC) levels are dynamic, depending on C additions and losses. Carbon is added from unharvested plant residues and roots, organic amendments, and erosional deposits. Carbon is lost through decomposition of organic materials and C transport via soil erosion. Conversion of native lands to agricultural production results in a 20 to 60% loss of SOC within 40 to 50 years.

IMPACT

Adequate soil organic carbon (SOC) levels are critical for agricultural productivity and contribute to carbon sequestration that can mitigate rising concentrations of greenhouse gases. Conversion of native lands to agricultural production results in a 20 to 60% loss of SOC within 40 to 50 years, but practices such as reduced tillage can partially restore these levels.

SOC levels vary widely across the REACCH region and within fields. The REACCH project is assessing this variability and the feasibility of using recently developed methods to quantify nutrient supplies and other soil health issues related to soil organic matter.

Agricultural practices that can partially restore depleted SOC include: (1) adoption of conservation tillage; (2) intensification of cropping by eliminating fallow, increasing cover crops, and including more perennial vegetation; and (3) improving biomass production through the use of soil amendments (manures), fertilizers, and high-yielding crop varieties. Rates of soil C sequestration following a change from conventional tillage (CT) to no-tillage (NT) are predicted to peak within 5 to 10 years, with SOC reaching a new steady-state 20 to 100 years following the management change or until soil storage capacity is reached. The SOC sequestration potential, rate of SOC accumulation, and time required to obtain maximum SOC are region- and site-specific.

Figure 1. Active soil organic matter, roots, and other soil biological constituents help bind soil particles together to form stable aggregates known as "peds."

Native SOC in the Palouse region of eastern Washington and northern Idaho varied considerably within a given landscape, ranging from about 2% on summit positions to almost 4.5% on north-facing foot slopes. Dryland agriculture has had a tremendous influence on native SOC, primarily due to shifts from perennial bunch grass-dominated vegetation to annual cropping, coupled with inversion tillage that has resulted in historical soil erosion rates of over 25 Mg soil yr-1. Previous research has estimated that 50 to 70% of SOC had been lost from upland soils.

The large variability in reported soil C sequestration rates and overall storage is a consequence of multiple factors, including: (1) initial levels of SOC and degree of system SOC saturation; (2) soil properties, such as texture and aggregation (Figure 1); (3) soil erosion; (4) artificial drainage; (5) soil disturbance and crop rotation; and (6) productivity and time. Field SOC heterogeneity occurs as a function of complex interactions of biological and physical processes (e.g., C inputs from crop residues and roots; soil organic matter (SOM) decomposition; and soil erosion processes). Greater understanding of field-scale variations in SOC and the processes and factors contributing to SOC dynamics is key to quantifying SOC sequestration, developing more sophisticated SOC models, and promoting improved land use and management decisions.

Recognizing that management impacts on SOC are primarily on the active, readily decomposable portions of total SOC, interest has grown among scientists and farmers regarding how this rapidly cycling SOC can be measured (Figure 2). While total SOM or SOC are standard soil tests, these tests are not always representative of the active soil C fraction that contributes to nutrient cycling, soil structural stability, and overall soil health. Consequently, scientists have been exploring measures that assess this more active pool of SOM to determine how management factors impact SOM dynamics. While a number of testing methods look promising, interpretation, sensitivity, speed, reliability, cost, and other factors must be assessed to identify measurements that are most useful. One goal of REACCH is to assess different SOC tests that aid quantification of nutrient supplies and other soil health issues related to SOM.

Overall objectives under REACCH regarding SOC are to: (1) continue to quantify agricultural impacts on SOC sequestration for dryland cropping systems in different agroecological zones (AEZs) of the Pacific Northwest; (2) characterize site-specific changes in SOC (0 to 1.53 m) due to management practices within fields typical of the region; and (3) assess chemical, physical, and biological methods of measuring active SOC pools.

In previous work, Brown and Huggins summarized management impacts on SOC storage across the dryland AEZs and associated farming systems from the known Pacific Northwest literature. They reported SOC changes under different soil management scenarios: native conversion, adoption of NT, and use

Table 1. *Summary of profile changes in soil organic carbon (SOC) calculated from the mean and cumulative probability function for native conversion, adoption of no-till (NT), and use of a mixed perennial-annual rotation.*

Management	AEZ[1]	Number of studies	Period covered by data (Mean years)	Mean SOC change[2,4]	Cumulative probability estimate of SOC change[3,4]		
				------------------ Mg C ha^{-1} yr^{-1} ----------------	25th	50th	75th
Native conversion							
	2	7	74	-0.84 (±0.17)	-0.70	-0.82	-0.92
	3	4	55	-0.53 (±0.18)	-0.35	-0.48	-0.58
	5	3	7	-0.69 (±0.52)	-0.14	-0.47	-0.80
No tillage							
	2	12	14	0.71 (±0.63)	0.21	0.64	1.04
	3	5	10	0.21 (±0.10)	0.12	0.19	0.25
Mixed perennial-annual							
	2	8	12	1.03 (±0.41)	0.69	0.94	1.12

[1] AEZ = Agroecological zone, where 2 = annual cropping, 3 = crop/fallow transition, and 5 = grain/fallow.
[2] Values in parentheses indicate plus or minus 1 standard deviation from the mean value.
[3] The 25th, 50th, and 75th percentiles of the cumulative probability function.
[4] To convert rate of SOC change from Mg C ha^{-1} yr^{-1} to the carbon trading units of metric tonnes of CO_2 equivalents per acre per year (MT CO_2e ac^{-1} yr^{-1}), multiply Mg C ha^{-1} yr^{-1} by 1.48277.

of a mixed perennial-annual rotation (Table 1). These analyses showed that 75% of converted native land lost at least 0.14 to 0.70 Mg C ha^{-1} yr^{-1} over an average of 55 to 74 years depending on AEZ. Converting from CT to NT was predicted to increase SOC at least 0.12 to 0.21 Mg C ha^{-1} yr^{-1} over 10 to 12 years in 75% of studies analyzed and was also AEZ specific. Compared to annual cropping, mixed perennial-annual systems would be expected to gain at least 0.69 Mg C ha^{-1} yr^{-1} over 12 years in 75% of AEZ 2 (annual cropping) sites. Regional assessments of active SOM pools in long-term REACCH study areas in each of three dryland AEZs as well as an irrigated site were initiated in 2013.

In addition to variability across the region, SOC and SOC responses to management can vary considerably within fields. Soil (0 to 1.5-m depth) at the Washington State University Cook Agronomy Farm (37 ha) was sampled and analyzed for SOC from a systematic, non-aligned grid of 177 geo-referenced locations in 1998 and again in 2008 after a 10-year conversion from CT to NT. Profile (0 to 153-cm) SOC from the 1998 sampling ranged from 54 to 272 Mg C ha-1 over the 37-ha field, and landscape SOC redistribution via soil erosion was evident (Table 2). Redistribution of SOC via erosion increases field SOC heterogeneity and must be quantified if SOC sequestration and management impacts are to be adequately assessed. Completion of analyses for the 2008 sampling will likely show that changes in SOC are greatly influenced by landscape and soil characteristics.

Figure 2. *No-till management positively impacts active soil carbon levels at the surface, thereby improving soil health. Photo by Fred McClellan.*

Table 2. *Soil series, taxonomic classification, field area, and soil organic carbon (SOC) on the 37-hectare Washington State University Cook Agronomy farm.*

Soil series (Field survey)	Taxonomic classification	Field area (%)	SOC (0–30 cm)[1] (Mg ha^{-1})	SOC (30–153 cm)[1] (Mg ha^{-1})	SOC (0–153 cm)[1] (Mg ha^{-1})
Staley	Fine-silty, mixed, superactive, mesic Calcic Haploxerolls	9	49a (20)	48a (38)	97a (25)
Naff	Fine-silty, mixed, superactive, mesic Typic Argixerolls	16	54ab (19)	69bc (35)	122bc (26)
Palouse	Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls	42	55b (17)	77cd (38)	132c (26)
Thatuna	Fine-silty, mixed, superactive, mesic Oxyaquic Argixerolls	25	59c (17)	84d (39)	143d (27)
Latah	Fine, mixed, superactive, mesic Xeric Argialbolls	7	59bc (21)	80bcd (39)	139bcd (27)
Caldwell	Fine-silty, mixed, superactive, mesic Cumulic Haploxerolls	1	59ns (1)	103ns (2)	163ns (1)
ALL		100	56 (18)	75 (40)	131 (28)

[1] Mean separation ($p \leq 0.1$) using Tukey; coefficient of variation (CV) in parentheses.

Intensifying grain legume production in dryland cropping systems

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Rotating grain legumes with wheat can help diversify grower incomes; break pest, weed, and disease cycles; and improve the use of nutrients. For this reason, grain legumes are common in crop rotations of the annual cropping zone (> 450 mm annual precipitation) of the REACCH region (Figure 1). In the grain-fallow zone (< 300 mm annual precipitation), alternative crops and rotations have not been as economically viable as traditional winter wheat-summer fallow. Nevertheless, winter and spring grain legumes may play an important role in the diversification and intensification of rotations in the annual crop-fallow transition zone (300 to 450 mm annual precipitation), as well as in the grain-fallow zone.

IMPACT

Grain legumes have the potential to improve nitrogen management in the low precipitation zones of the REACCH study area. This project will: (1) provide science-based evidence for intensifying grain legume production in dryland cropping systems, and (2) improve dinitrogen fixation and overall cropping system nitrogen use efficiency.

Recent evidence of greater interest and adoption of grain legumes is provided by the Cropland data layer, where from 2007 to 2012, the prevalence of pea, lentil, and chickpea has increased by 73% in the annual crop-fallow transition zone and by 56% in the grain-fallow zone. Cool-season grain legumes have been successfully adapted into rotations in Mediterranean-like regions of southwestern Australia that receive less than 350 mm annual precipitation. Faba bean and field pea have demonstrated tolerance to water-limited conditions via early biomass and pod production and shorter growing seasons, producing yields comparable to wheat.

Our REACCH findings suggest that grain legumes have the potential to improve nitrogen (N) management throughout the REACCH study region in the low precipitation zones. In a current 3-year study located in the annual crop-fallow transition zone of eastern Washington, the effects of spring pea included boosting subsequent winter wheat grain yield by 18% and improving the N balance by 20 lb N/acre, comparable to observations common in the annual cropping zone (data not shown). Spring pea yields from 2011 through 2013 averaged 1,618 lb/acre in the annual crop-fallow transition zone (Davenport, Washington) and 1,563 lb/acre in the annual cropping zone (Pullman, Washington). However, the standard deviation in yields was twice as high in the intermediate zone. The estimated quantity of N derived from biological fixation was less than 50% of total plant N in this zone, unlike the high rainfall zone (Figure 2). Most of this N is likely to be exported in the seed. The contribution of biological N_2 fixation to the rotation depends on selection of properly adapted legume varieties and the efficiency of rhizobia inoculum.

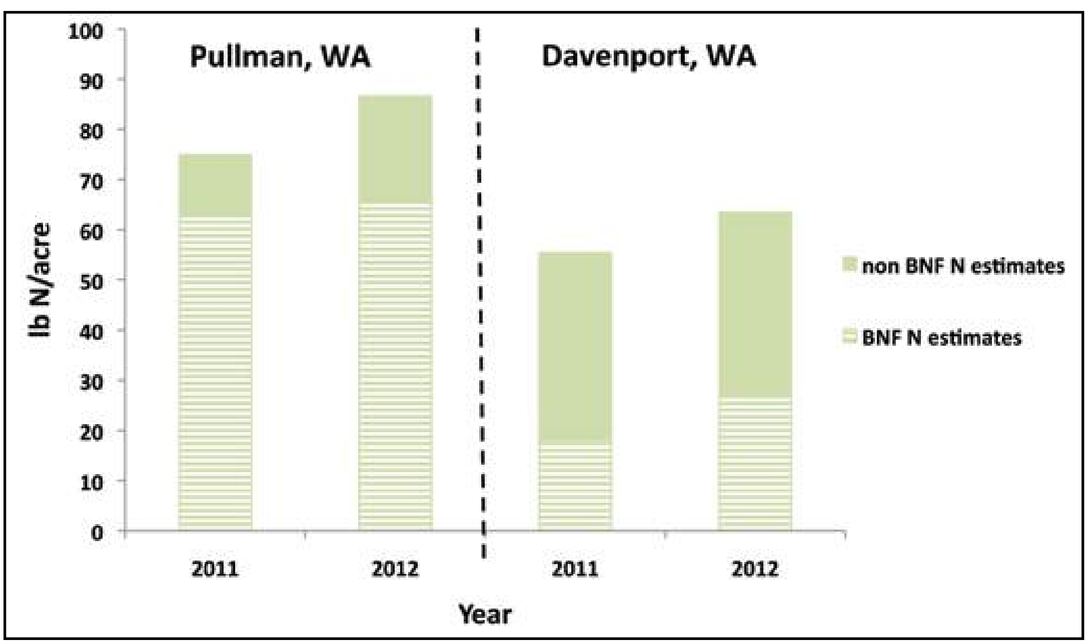

Figure 2. *Above-ground nitrogen (N) in spring pea crops at Pullman, Washington (high rainfall zone) and Davenport, Washington (intermediate rainfall zone) in 2011 and 2012. Biological N_2 fixation (BNF) estimates were calculated using a N difference approach relative to a spring wheat reference crop.*

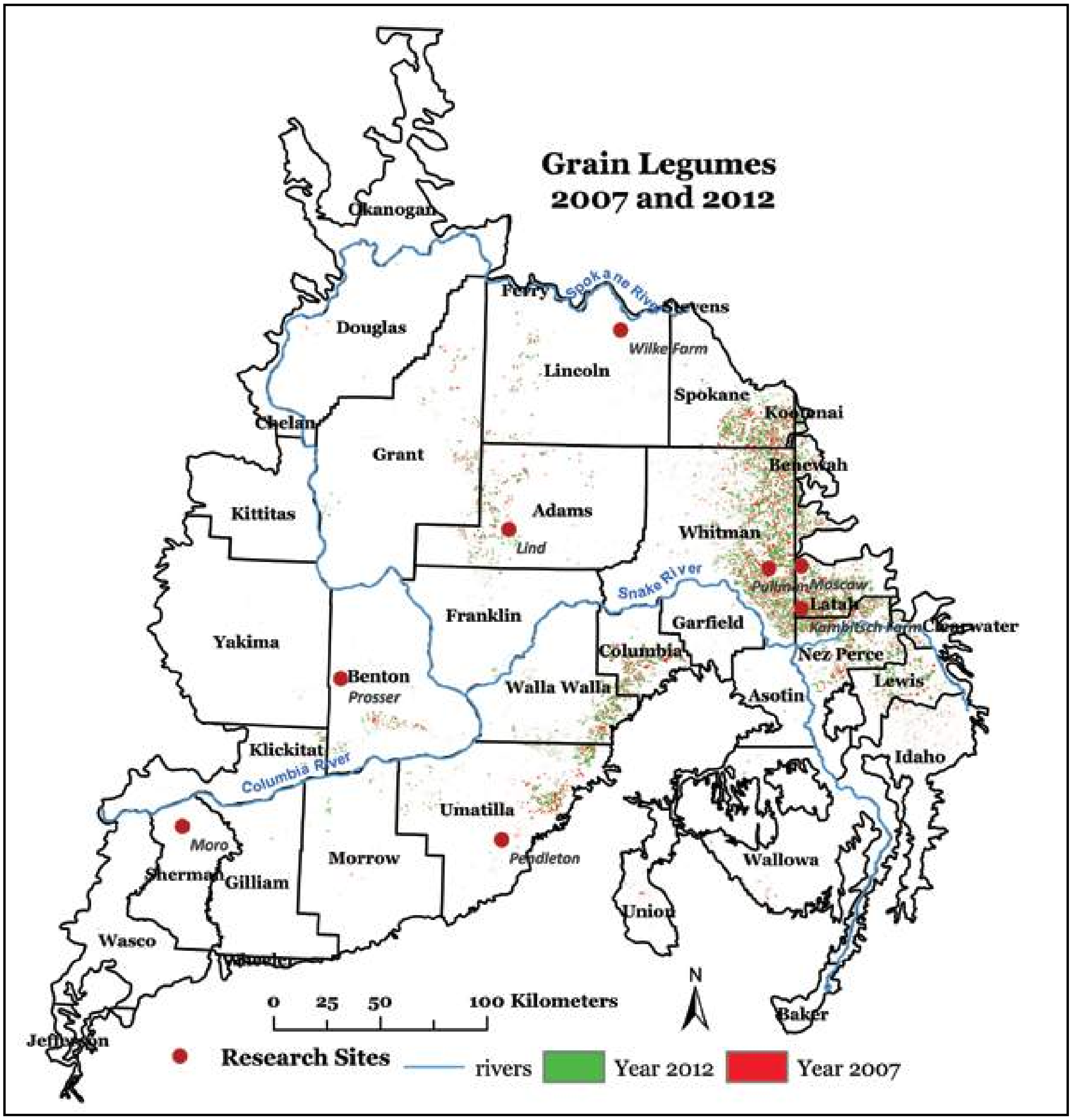

Figure 1. *Grain legume production area (2007–2012) in the REACCH region.*

In an ongoing field study near Ritzville, Washington (290 mm annual precipitation), winter pea has produced an average yield of 2,288 lb/acre when grown in a 3-year winter pea-spring wheat-summer fallow rotation (data not shown). In the second year of the study, spring wheat grain yield following winter pea was greater than that following winter wheat in a 3-year winter wheat-spring wheat-summer fallow rotation. Winter pea uses significantly less soil water than winter wheat (data not shown), and we think this will result in greater spring wheat grain yield following winter pea as the study progresses. Periodic substitution of winter pea for winter wheat will diversify rotations and give farmers an excellent opportunity to manage problematic grassy weeds such as downy brome and jointed goatgrass.

There is evidence that biological N_2 fixation may be increased in the short-term by (1) inoculating legumes more frequently, (2) inoculating with more effective, competitive rhizobial strains that produce more nodules, (3) co-inoculating with "helper organisms," (4) selecting legume varieties that support rhizobial infection, and (5) genetically engineering crops to enhance nodule size and number based on variety by strain interactions. Information found in published literature shows that significant yield increases of up to 100% as a result of inoculation of virgin soils have been observed. In addition, repeated inoculation of some crops is required when a new legume is introduced into a soil that is unlikely to contain enough rhizobia for effective root infection. Depending on soil nitrate and other conditions, a 33 to 50% yield improvement on average was achieved by inoculating all grain legumes at every planting. Our future research aims to: (1) quantify the rhizobial populations in pea currently grown in the REACCH region, (2) assess the viability of *Rhizobium leguminosarum* bv. viciae. inoculum under various crop rotation and tillage practices, and (3) further assess conditions where rhizobial inoculation is beneficial for pea.

Nitrogen cycling in crop rotations

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Improving nitrogen (N) use efficiency is a key strategy for mitigating climate change in the REACCH region, which is delineated by distinct environments and cropping systems. Continuous annual cropping prevails in wetter areas (> 450 mm annual precipitation), with legume crops commonly rotated with spring and winter cereals. In warmer, drier areas (< 300 mm annual precipitation), a grain-fallow rotation persists. An annual flex, or crop-crop-fallow transition zone bridges relatively wet and dry areas (300 to 450 mm annual precipitation).

IMPACT

The improvement of nitrogen use efficiency in cropping systems is a key strategy for mitigating climate change in the REACCH region. In the grain-fallow cropping system, the application of REACCH research findings has the potential to at least partially offset the effects of drought stress, low nitrogen uptake efficiency, and a shortened grain filling period predicted by some climate change models.

Along a precipitation gradient, water and N may interact in predictable ways, and so we might expect variations in N use efficiency across the REACCH region. A conceptual diagram of the relationship between annual precipitation and N use efficiency is presented as a curved line in Figure 1. In this diagram, N use efficiencies are predicted to be reduced in the grain-fallow system (< 300 mm) due to drought stress, low uptake efficiency, and a shortened grain filling period. Dry spring conditions can leave soil N "stranded" as root activity near the surface is impaired. Nitrogen use efficiency can also be diminished with increasing annual precipitation (> 600 mm) due to nitrate leaching from the root zone and denitrification. Therefore, hypothetically, N use efficiencies are thought to be maximized in the transition and drier portions of the annual cropping zones (300 to 600 mm).

However, this interpretation of N use efficiency along a rainfall gradient only considers N dynamics over a single season. It ignores the potential for N to be retained by soil organic matter, thus preventing N loss through leaching or denitrification and allowing N to be absorbed by crops during subsequent seasons. Furthermore, the hypothetical model disregards the effects of crop residues on N availability for following crops, as well as the effects of more effective timing of N fertilizer application on N use efficiency. (As annual precipitation increases, N application shifts from winter to spring.)

Rotational observations or totals for N use efficiency may be more useful when analyzing the effects of N management and cropping history on N retention and availability of the system. Rotational approaches to assessing N use efficiency include: (1) N balances; (2) N use indices; and (3) net mineralization estimates. Partial N balances calculate the difference between inputs of N (e.g., fertilizers) and N outputs (e.g., grain harvest) over the entire rotation. Rotational N use indices describe the efficiencies of the cropping system, or the sum quantity of grain that is obtained for a given rotational N supply. Finally, net N mineralization estimates the amount of inorganic N that accumulates over the entire

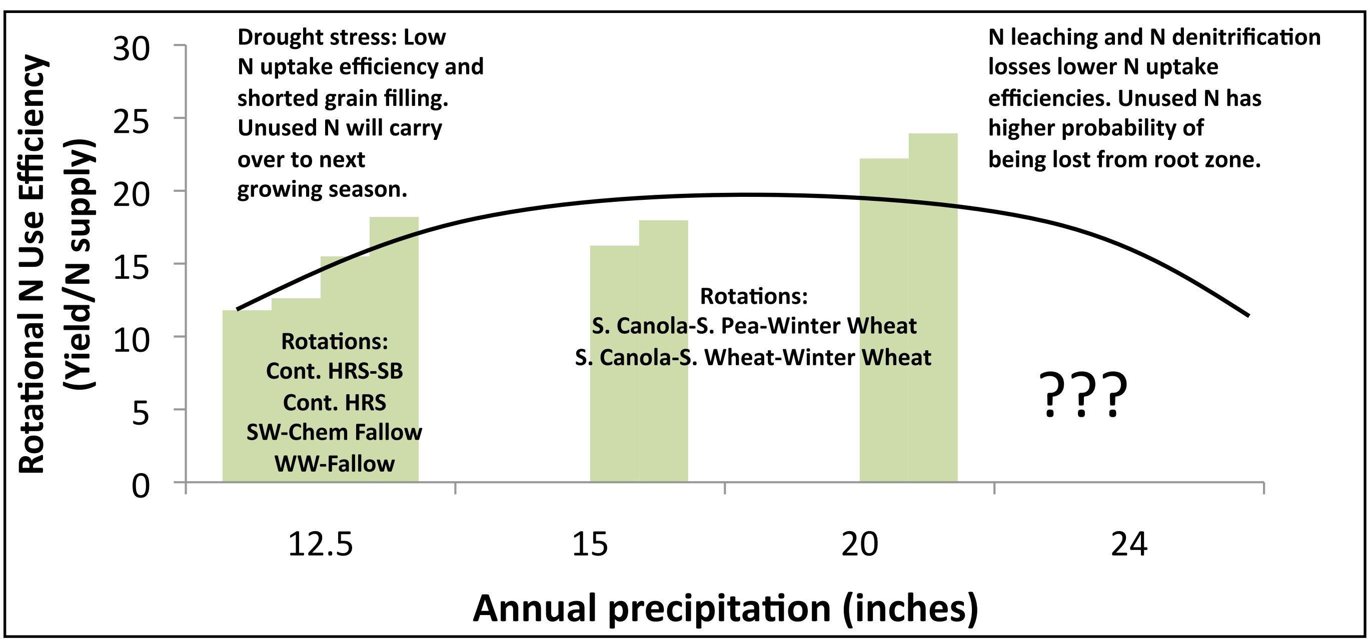


Figure 1. *Nitrogen use efficiencies for alternative wheat crop rotations in different rainfall zones of the inland Pacific Northwest. Adapted from a conceptual relationship between nitrogen use efficiency and rainfall zones. Cont. = Continuous cropping. HRS = Hard red spring wheat. SB = Spring barley. Chem Fallow = Chemical fallow. WW = Winter wheat. S = Spring.*

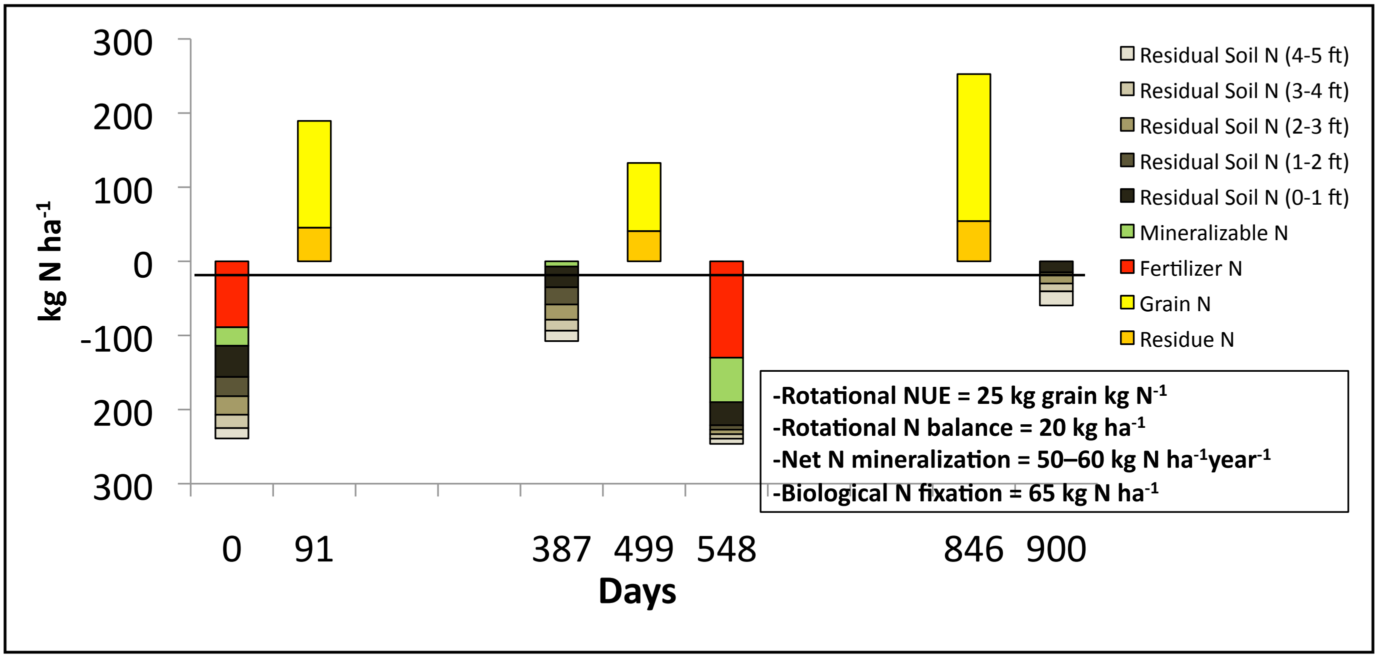


Figure 2. *Changes in grain, crop residue, and plant-available soil nitrogen (N) during a 3-year rotation of spring canola/spring pea/winter wheat in the high precipitation zone. Estimates are provided for crop sequence nitrogen use efficiency (NUE), rotational N balances, and biological N fixation (BNF). NUE = total yields/total N supplied. Rotational N balances = (N fertilizer + N mineralization + biological N fixation) – (total grain N exports + residual soil inorganic N). BNF = (plant N – change in soil N relative to an unfertilized spring wheat reference crop).*

rotation. Internal N cycling may enhance N use efficiencies over multiple years under increasing precipitation (Figure 1). We aim to incorporate REACCH data from replicated field sites to corroborate this hypothesis in the upcoming year.

Our team has adopted a multiple-year N budget approach to track N dynamics over 3-year cropping sequences (e.g., spring canola-spring pea-winter wheat; spring pea-spring wheat-winter wheat) in the annual cropping and crop-fallow transition zones. In the spring canola-spring pea-winter wheat cropping sequence, our N budgets indicate that spring canola, like winter wheat, is an effective N scavenger (Figure 2). After both canola and winter wheat crops, residual nitrate is less than 50 kg N/ha in the top 4 feet of soil, compared to more than 60 kg N/ha following spring peas. While the soil N supply (e.g., inputs of N fertilizer, pre-plant soil N, and net N mineralization) often exceed grain N exports for the entire rotation, the amount of N remaining in crop residues after harvest accounts for 8 to 40% of the total N inputs and is not subject to immediate loss. Furthermore, residual inorganic N remaining after canola and winter wheat represents 10 to 33% of the total N supplied to the crops.

Including field peas in rotation can enhance N outputs by 15 to 50 kg N/ha, as compared to the reference rotation with wheat, presumably due to biological N fixation. However, more residual and leachable inorganic N remains after pea harvest. This N is readily available to the following winter wheat crop, amounting to approximately half of the pre-plant N supply.

Nitrogen use indices show that winter wheat is a more efficient overall N user than canola, but has a relatively greater dependence on fertilizer N. Peas reduce the overall reliance on fertilizer through biological N fixation, while residual inorganic N is able to satisfy a greater proportion of canola's N requirement at yield-optimizing fertilizer rates.

In this rotation, the proceeding crop species and N fertilization resulted in apparent differences in net N mineralization, or the accumulation of inorganic N, of 20 kg N/ha or less in soil cores (0 to 6 inches) collected from the field (data not shown). Soil organic matter plays an important role in N cycling, primarily through mediating N mineralization and immobilization (e.g., release/absorption) of inorganic N. Soil organic matter content is enriched with nitrogenous compounds, and can serve as an important potential sink for fertilizer N. Based on knowledge of soil organic matter turnover, we would expect a net release ranging from less than 20 kg N/ha in a soil that has 1% organic matter under reduced tillage to 55 kg N/ha in a soil with 3% organic matter.

The addition of fresh organic sources, such as plant residues, is known to enhance or reduce N availability, depending on residue quality and decomposability. A rule of thumb is that net mineralization, or release, of N occurs when C:N ratios of fresh plant material are less than 25:1, with a net release of N over a season expected for residues ranging from 10:1 to 24:1. However, cereal crop residues tend to have C:N ratios well above 25:1, and a greater quantity of residue can remain after winter crop harvests. Dissimilarities in crop residue quality and quantity could contribute to differences in short-term N cycling following one crop compared to another. In the long term, continual additions of crop residues help maintain soil organic matter, sustain N cycling from fertilizer and crop residue sources, and prevent fertilizer N losses from the cropping system.

Precision nitrogen management: Developing science-based practices

Dave Huggins (David.Huggins@ARS.USDA.gov) USDA-ARS, Jake Wavrin WSU, David Brown WSU, Aaron Esser WSU, and Kate Painter UI

Increasing nitrogen (N) use efficiency (NUE) through the use of precision technologies (e.g., GPS, remote sensing, yield monitors, and variable rate application) will require increased scientific understanding of landscape-scale processes and their impacts on decision making (Figure 1). Specifically, we are assessing yield-water-NUE relationships among diverse environments to elucidate site-specific processes that regulate the environmental and economic performance of wheat-based cropping systems. This effort will produce grower-oriented, site- and time-specific tools required to formulate N-efficient and environmentally sound conservation strategies, including tools for N management monitoring, decision making, and evaluation.

IMPACT

Our expectations are to develop science-based decision aids that improve the application of precision nitrogen management strategies in wheat. Specifically, we seek advances in the determination of economic management zones, precision nitrogen application rates, and site-specific assessments of wheat performance (crop and economic evaluation).

Stakeholders include growers, researchers, students, the public, and policy makers interested in the science and methodology of increasing NUE in dryland cropping systems of the REACCH region. Integration with economic and crop modeling efforts, as well as with the Site-Specific Climate Friendly Farming project (funded by the U.S. Department of Agriculture, National Institute of Food and Agriculture), is essential and on-going.

Our overall goal is to develop science-based decision aids for the application of precision N management strategies in wheat. In particular, application of precision technologies and strategies require advances in the determination of economic management zones, precision N application rates, and site-specific assessments of wheat performance (crop and economic evaluation). We are pursuing this goal through the integration of crop (e.g., yield monitoring), soil (e.g., apparent electrical conductivity), remote-sensed (e.g., Rapideye satellite imagery), and economic data using field-scale studies at the Washington State University Wilke Farm and Cook Agronomy Farm and at on-farm locations. More specifically, we are: (1) measuring field-scale, site-specific wheat performance and related variables (yield, protein, economic return, N status, NUE, soil organic matter, and inorganic N) required for precision N management decisions, and (2) developing and

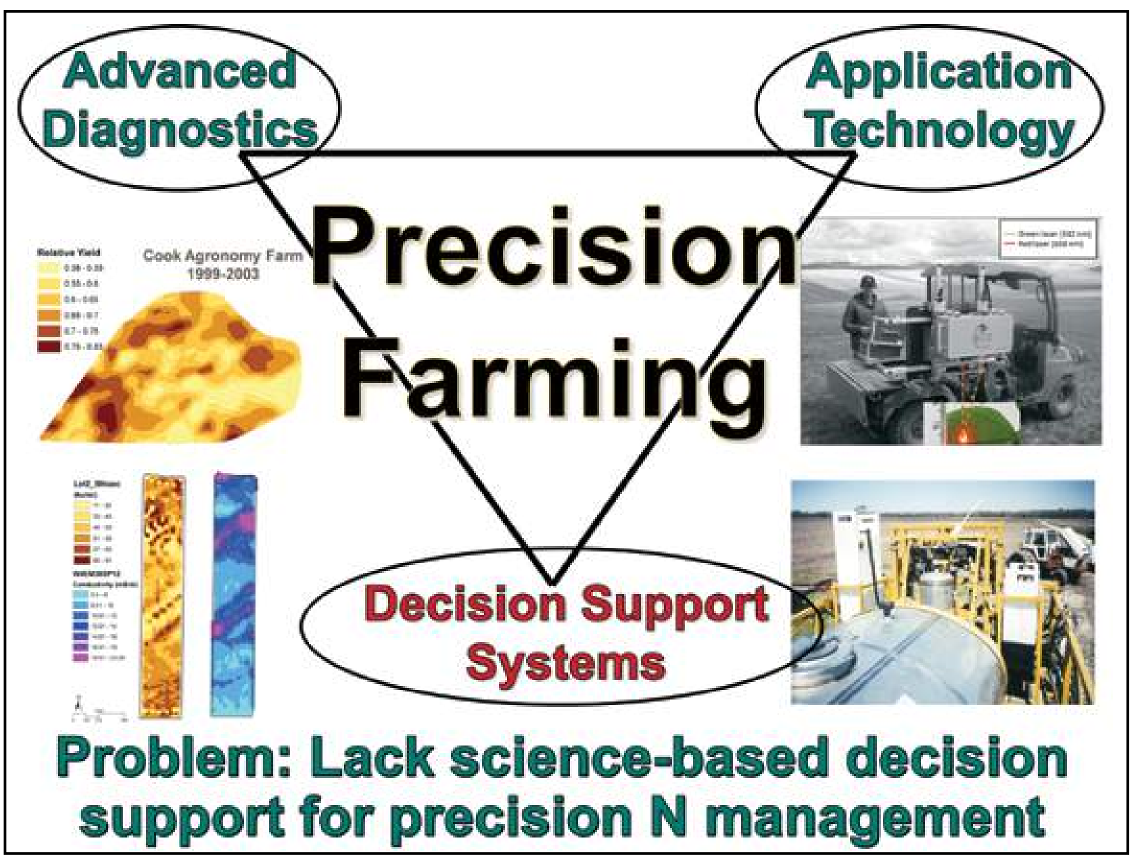


Figure 1. *Successful adoption of precision farming requires that advanced field diagnostics and application technologies be coupled with science-based decision support systems.*

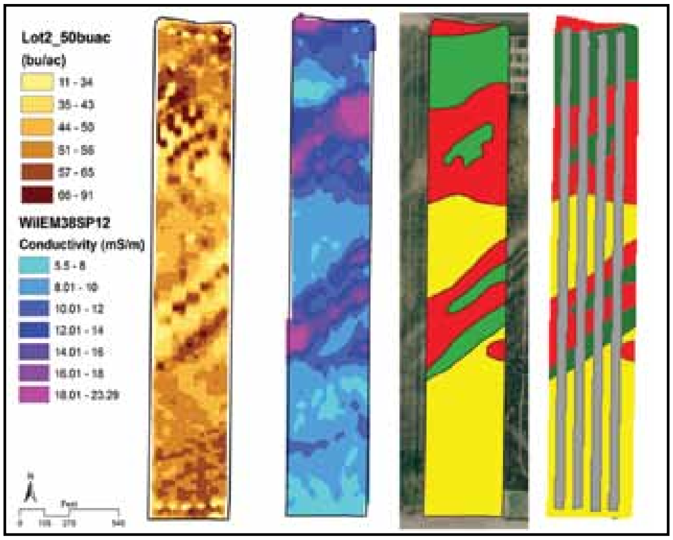
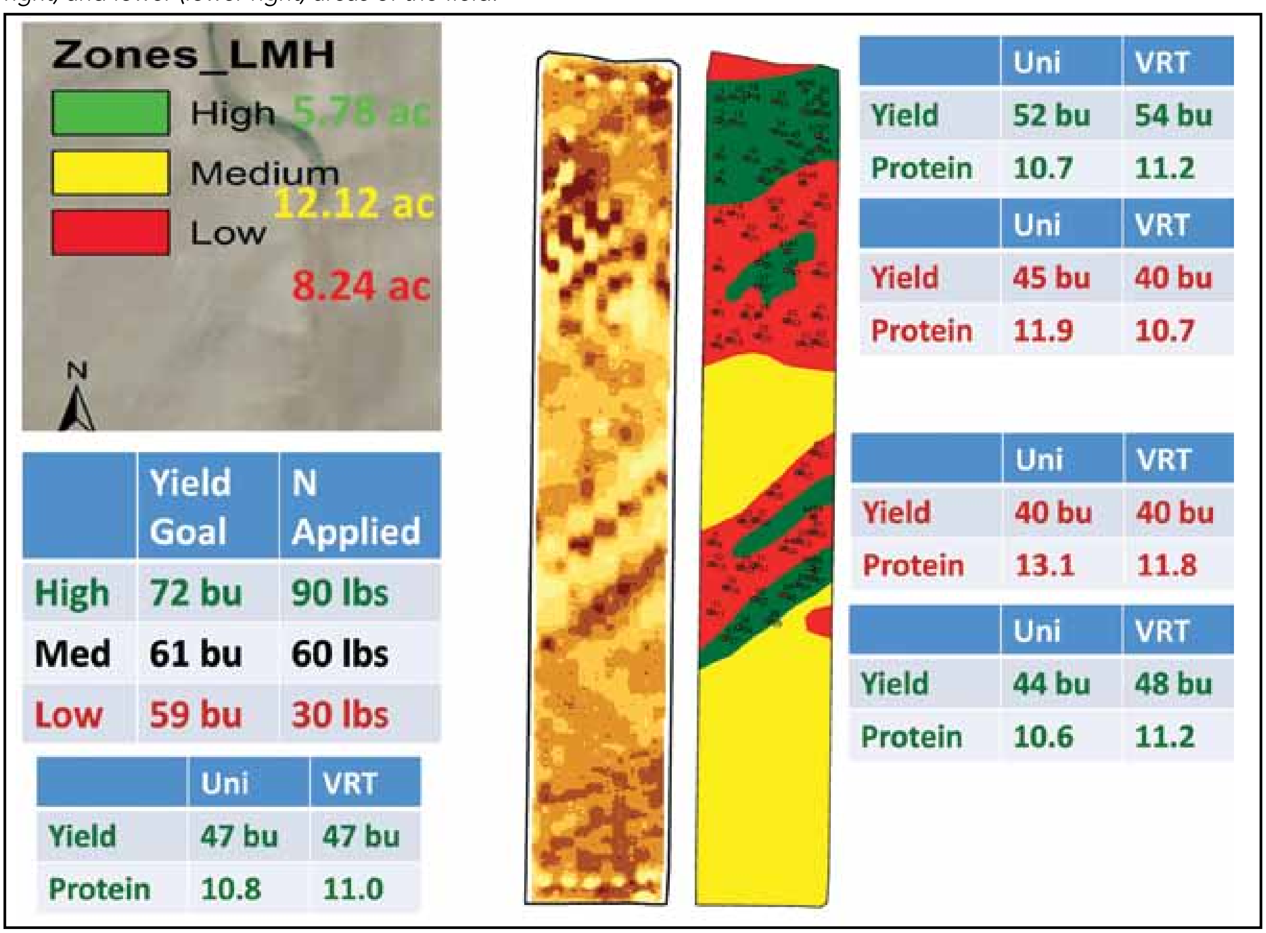


Figure 2. *Grain yield monitor (A) and apparent electrical conductivity data (B) from a 26-acre Wilke Farm field were used to create nitrogen management zones (C) with high (green), medium (yellow), and low (red) yield goals. Control strips with uniform applications of nitrogen are depicted in gray (D).*

Figure 3. *Yield goals, applied nitrogen, and resultant yield and grain protein concentrations. Actual yield and protein at the field level is shown on the lower far left, with a comparison between uniform (Uni) and variable rate (VRT) nitrogen application. Tables on the far right compare actual yield and protein by zones (green for high, red for low) for upper (upper right) and lower (lower right) areas of the field.*



testing site- and time-specific decision-aid and evaluation tools, including an economic assessment required by growers to formulate and assess science-based precision N recommendations.

A 26-acre strip at the Wilke Farm was used for a precision N study in 2012. Grain yield monitor (1 year) and apparent electrical conductivity (Geonics EM-38) data were used to establish three N management zones with low, medium, and high yield goals (Figure 2). Variable rate N was applied during seeding of hard white spring wheat. Overall field averages for yield and protein were very similar for the two N application strategies (Figure 3). The N balance index (N removed in harvested grain divided by N fertilizer applied) was greater for the variable rate (VRT) treatment (0.99) as compared to the uniform (Uni) treatment (0.82). Preliminary economic analyses show that the VRT strategy was more economical on three of four "high" zones and two of three "low" zones.

Other data still under assessment include field soil water and inorganic N from comparative point samples as well as satellite imagery. These data will be used to further assess N and water use efficiency as well as the effectiveness of defining the three VRT zones. We repeated a similar experiment on this field, as well as another field at the Wilke Farm, in 2013. In addition, precision farming strategies are also being evaluated at the Cook Agronomy Farm and on four on-farm locations as part of the Site-specific Climate Friendly Farming project (SCF) led by Dr. David Brown (Washington State University).

Cover crops, soil conservation, and prevented planting acres

David Steury (contact kpainter@uidaho.edu) UI

As agricultural producers around the world are acutely aware, climate, cropland quality, and profits are inextricably intertwined. In the REACCH area, precipitation amounts are expected to increase by 5 to 15% in the next 40 to 70 years, and wet springs are expected to become more common (Figure 1). The timing of spring precipitation increases will have an impact on spring plantings.

In the Palouse region, which comprises a large subsection of the REACCH study area, excess springtime moisture can lead to crop insurance claims for prevented planting. Prevented planting coverage insures producers against instances in which they are unable to put seeds in the ground for an insurable reason. Under such a circumstance, prevented planting provisions generally pay out 60% of the total insured amount. Producers are then restricted from harvesting a crop from the land for which they took an indemnity until November 1 or later without a reduction in benefits (e.g., a producer would receive only 30% of the prevented planting coverage). The parcel can be left fallow or planted to a cover crop, but the cover crop cannot be harvested without incurring the penalty.

IMPACT

Predicted increases in spring precipitation and resulting impacts on spring plantings due to excess springtime moisture can lead to crop insurance claims for prevented planting, often with negative financial implications to the farmer. Fallow ground is more susceptible to erosion. When erosion increases, future yields and profits drop. The proper use of cover crops conserves soils on erodible land, improves soil structure, and tends to slow or reverse some of the impacts of modern intensive farming practices.

No year is more illustrative of the effects of excessive spring precipitation than 2011, when an unusually wet spring triggered prevented planting claims on more than 122,000 acres in the REACCH area. After the final planting date, most producers decided to summer fallow the parcels on which they took prevented planting, which led to increases in soil erosion on these parcels.

The Palouse is characterized by rolling loess hills (Figure 2). The topsoil in the Palouse is deeper than any other in the world. This soil, originally deposited by wind, is highly erodible. Under normal weather conditions, cropland in the Palouse erodes at a comparatively high rate (Figure 3). Under conditions of increased spring precipitation, these rates could increase. Without roots in the ground to help retain soil, already severe sheet and rill erosion on the Palouse's hilly terrain turns into more severe gully erosion.

Heavy erosion is unsustainable for long-term productivity. As valuable topsoil erodes away, yield and profits drop. The Palouse is a special case in that it has so much topsoil that it is much more resilient to erosion than other less fortunate locales. But this does not mean that producers in the area are not concerned with erosion.

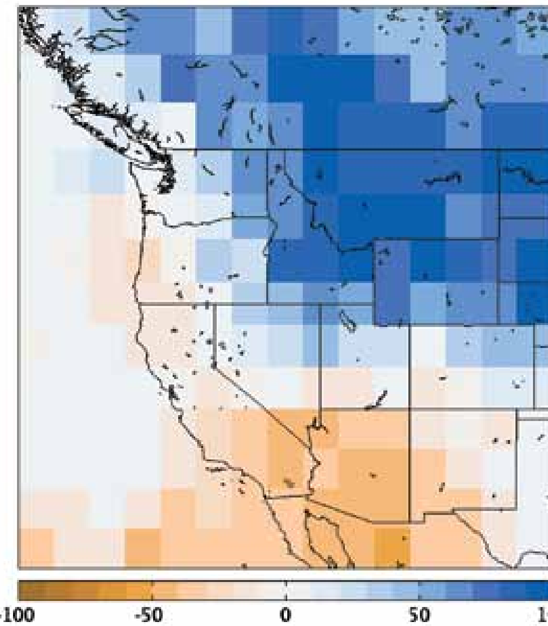


Figure 1. *Projected percentage change in the frequency of wet springs (March through May) for 2031 through 2060 as compared to contemporary climate (averaged from 28 climate models run under experiment RCP 8.5). Wet springs are defined as being among the wettest 20% of springs. The models hint at more frequent wet springs in a changing climate. No change would correspond to a value of 0. Blue indicates an increase in frequency of wet springs; orange/brown indicate a decrease.*

The proper use of cover crops has been repeatedly shown to conserve soil on erodible land, to improve soil structure, and to generally slow or reverse some of the impacts of modern intensive farming practices. The Natural Resources Conservation Service estimates that, accounting just for sheet and rill erosion, as opposed to more destructive gully erosion, cover crops planted on otherwise fallow ground will retain 4 to 5 tons of soil per acre.

Based on the high rate of prevented planting claims in the Palouse region during the high rainfall year in 2011, it was hypothesized that prevented planting claims may be correlated with springtime rainfall. Using claims information provided by the U.S. Department of Agriculture (USDA) Risk Management Agency and annual precipitation data from the National Oceanic and Atmospheric Administration, a statistical model linking rainfall to prevented planting claims was developed for the Palouse region. The results from the analysis are consistent with the expectation that higher springtime precipitation leads to more frequent prevented planting claims. The analysis shows a correlation between prevented planting acreage and annual precipitation. Creating a true predictive model would require accounting for other influences such as springtime temperatures, seasonal precipitation, prices, and other policy variables.

Nonetheless, the expected increase in precipitation over the next several decades could lead to increases in prevented planting claims and erosion rates similar to 2011. During that year, erosion rates were estimated to be as much as 50 tons per acre on some fields. According to the USDA, each ton of soil eroded in the Pacific farm production region has a negative economic impact of $0.53. Combating soil erosion from weather events will help ensure long-term productivity and profitability. One way to do this would be to plant cover crops on prevented planting acreage, which would reduce erosion and increase soil quality on land that lies fallow.

Figure 2. *The Palouse region. Photo courtesy of Stone-Buhr Flour Company.*

Figure 3. *Winter erosion after winter wheat harvest, direct seed versus conventional tillage. Photo by Bill Jepsen.*

Strategies for wheat producers facing climate change

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Climate change researchers project that fall and winter rainfall will increase in the Pacific Northwest. These changes pose interesting management decisions for wheat farmers in the low rainfall regions of the Pacific Northwest.

Wheat regions in the Pacific Northwest can be separated into three precipitation zones based on annual precipitation: less than 12 inches, 12 to 18 inches, and 18 to 24 inches. Where annual precipitation is less than 12 inches, a wheat/fallow rotation is followed. In the 18- to 24-inch zone, continuous cropping is practiced, with wheat as a crop option. In the 12- to 18-inch zone, crop options range from a wheat/fallow rotation to crops grown on an annual basis, depending on soils and management. The general trend toward increased winter precipitation increases the possibility of successfully planting on an annual basis within the 12- to 18-inch precipitation zone. Some farms within this zone already successfully plant on an annual basis and are interested in adding diversity to their operations by adding peas or biofuel crops such as canola and camelina into their rotations (Figures 1–3).

IMPACT

AgTools™ allows farmers to better understand financial and planting options, as well as associated impacts to farm profitability under uncertain future climates, technologies, and prices. With predicted increases in winter precipitation, there is a trend to diversify and add biofuel crops such as canola and camelina into rotations. Experiments with crop rotations that incorporate biofuel crops have shown promise for the potential of increased wheat yields and increased net returns. For the representative farm studied, the additional investment in machinery to switch to a continuous cropping system of winter wheat and canola would generate higher profits.

REACCH researchers recently set up a case study to demonstrate how AgTools™ software can be used to evaluate the profitability and feasibility of such changes in crop rotations at the individual farm level. This software is designed to analyze a farm's liquidity, solvency, profitability, and repayment capacity. This case study was set up to represent a plausible farm in eastern Oregon that receives an average of 16 inches of rainfall annually. It is representative of a 3,800-acre wheat farm that currently follows a winter wheat/fallow rotation on 1,425 acres each year using direct-seeding (no-till) practices. Half of the acreage is cropped each year, and the other half is left in chemical no-till fallow to conserve soil moisture, reduce soil erosion, and reduce fuel usage. Additionally, 475 acres are planted to spring wheat. Thus, each year, the farm has 1,425 acres in winter wheat and 475 acres in spring wheat following 1,900 acres of fallow.

Most farms in this zone practice summer fallowing to capture moisture in the fallow phase to increase crop yield in a dry year and reduce crop yield variability. On shallow soils that are unable to store substantial moisture, such as the north, east, and south fields from the case study, fields are not fallowed even though yields are low. Some farms in the same precipitation zone crop wheat annually on deeper soils, and climate change is expected to make this practice more common in the region.

The increased winter precipitation anticipated with climate change is expected to increase wheat yields. However, researchers in the REACCH project have estimated that the annual variability in wheat yields could increase by as much as 20 percent with higher incidences of insects and wheat diseases. Also, experiments with crop rotations that incorporate biofuel crops have shown promise for the potential of increased wheat yields and increased net returns.

In the past, the grower felt the added equipment expense for this farm, along with labor and input costs, did not justify the marginal annual sales generated from switching to annual cropping of wheat or other crops. However, costs have been rising over the past several years, and the farm's net income has been declining each year. Thus, the grower has decided to examine the feasibility of alternative cropping rotations.

University research and Extension faculty, industry representatives, and agricultural lenders were consulted to obtain current loan and balance sheet information, along with expected future yields and prices for winter wheat, spring dry peas, winter canola, and camelina over a 10-year period. This information was inputted into the AgTools™ software to conduct an economic assessment of the various cropping rotation options to determine how changes in input and output costs and changes in projected debt-

Figure 1. *Camelina is an ancient oilseed crop with new potential. Photo by Darrin Walenta.*

Figure 2. *Canola seed produces an oil that can be used for fuel or for cooking. Photo by Lynn Ketchum. Copyright Oregon State University.*

to-asset ratios would impact the financial position of this representative farm in the future. In addition to the changes in inputs and outputs associated with changing to a continuous cropping system, the farm also needs to obtain a $325,000 loan to purchase an additional tractor and combine to complete the farming operations in a timely manner. Three alternative crop rotations were considered: winter wheat followed by dry peas, winter wheat followed by canola, and winter wheat followed by camelina. The cash flow was estimated for each of the owned and leased fields on the farm to project net income on the farm.

The projected net incomes from each crop rotation are presented in Table 1. Using an 8% discount rate, the net present values were calculated to determine the most profitable crop rotation.

Table 1. *Projected net income by crop rotation.*

Year	Winter wheat after fallow ($)	Winter wheat after dry peas ($)	Winter wheat after canola ($)	Winter wheat after camelina ($)
1	244,906	522,832	664,281	397,894
2	298,928	561,775	707,287	432,717
3	215,082	475,814	618,582	346,946
4	365,832	636,995	783,688	503,615
5	161,414	433,013	577,182	299,976
6	279,959	560,404	708,352	422,441
7	123,757	411,458	557,113	273,998
8	263,903	549,945	699,222	407,118
9	131,694	414,753	561,984	272,601
10	227,091	514,298	664,987	366,313

The results are presented in Table 2. From a profitability perspective, a continuous winter wheat and canola cropping system was the most profitable across all field types on the farm. The second most profitable system on the north and east fields was winter wheat and camelina, while winter wheat after dry peas fared slightly better on the leased south and west fields. Looking at the feasibility of each cropping system on a whole-farm basis, the winter wheat following canola cropping system generated higher net incomes, lower debt-to-asset ratio, and higher current ratios over the 10 years. Thus, the additional investment in machinery to switch to a continuous cropping system of winter wheat and canola would generate higher profits for this farm then their current practices.

As shown by this example, AgTools™ provides a useful decision tool for growers. It allows them to better understand financial and planting options, as well as associated impacts to farm profitability under uncertain future climates, technologies, and prices.

Table 2. *Net present value of 10 years' net returns for possible crop rotations by field.*

	Net present value at an 8% discount rate ($/acre)			
Crop rotation	North field	East field	West field (leased)	South field (leased)
Wheat after fallow	639	1,113	231	65
Wheat after dry peas	231	65	589	490
Wheat after canola	1,466	2,039	758	669
Wheat after camelina	953	1,490	431	319

Figure 3. *Yellow fields of canola create a patchwork landscape where growers rotate crops to help reduce soil erosion and increase net returns. Photo by Brad Stokes.*

Wheat production challenges and opportunities: Creating a baseline

Kate Painter (kpainter@uidaho.edu) UI, Hilary Donlon Davis UI, and Dennis Roe WSU

Forty-eight wheat farmers across various wheat production areas of the inland Pacific Northwest are participating in a 4-year in-person survey that collects detailed annual data on their social, economic, agronomic, biotic, and climatic challenges. This is a unique approach to grower involvement and data collection that allows REACCH scientists to interact among themselves and to transcend their disciplines as they observe patterns across the region.

IMPACT

The longitudinal survey will gather social, economic, agronomic, biotic, and climatic data from a set of 48 growers distributed across the REACCH study area for 4 years. Farming differs each year, so the longitudinal approach will provide a more representative sample of how production differs by grower, by year, and by sub-region. Detailed feedback from growers helps scientists better understand their challenges and the best ways to help them deal with the challenges of climate change.

Participating farmers answer both a fixed and a new set of REACCH scientists' questions each year, regarding wheat production practices and timing, technology use, pests, university Extension services, demographics, and more. Insect pests and earthworm populations are sampled at different times at these growers' farms. Details of each farming operation are recorded in the grower surveys, such as timing of tillage operations, planting and harvesting dates, and pest outbreaks. This holistic approach will help scientists understand agroecological impacts and trade-offs of different farming practices by zone across this region.

Four agroecological zones are delineated across our study area (Figure 1). Zone 1, the dryland annual cropping area, typically receives 21 inches or more of precipitation annually. Average farm size for the surveyed growers in this zone was just over 2,500 acres. Average winter wheat yield was 91 bu/acre in 2011 (a year with higher than average rainfall) and 83 bu/acre in 2012 (Figure 2).

Zone 2, the intermediate area, is the transitional zone between annual cropping and the grain/fallow zones. Growers in this zone typically plant winter wheat following summer fallow, with a spring cereal crop following winter wheat production. Rainfall varies from approximately 15 to 20 inches of annual precipitation. Average farm size for surveyed growers in this zone, at 3,128 acres, was about 25% higher than in the annual cropping zone. Winter wheat yields averaged 83 bu/acre in 2011, about 10% less than in Zone 1, and 78 bu/acre in 2012, about 6% less than in Zone 1 (Figure 2).

Zone 3, the grain/fallow region, is typified by large farms (averaging more than 6,000 acres for the growers in our survey), low rainfall (9 to 15 inches annually), and low yields. This zone comprises the largest percentage of the farmland in the study area, but has the lowest productivity and presents many challenges to growers, from economics to weeds and wind erosion. An analysis of soil-disturbing passes for the surveyed growers revealed that Zone 3 had, on average, 2.1 soil disturbances for winter wheat production, compared to 1.62 for Zone 2 and 1.71 for Zone 1. Yields for Zone 3 averaged 65 bu/acre in 2011, a year of record precipitation for most growers in this zone, and 47 bu/acre in 2012, which was a more typical precipitation year (Figure 2). These yields are considerably lower than the yields in Zones 1 and 2; 2011 yields in Zone 3 averaged just 71 and 78% of the yields in Zones 1 and 2, respectively, while 2012 yields in Zone 3 averaged 56 and 60 % of the yields in Zones 1 and 2, respectively.

Zone 4 refers to irrigated winter wheat production and includes farmland in central Washington that is part of the Columbia Basin Irrigation Project. Just two irrigated wheat growers are

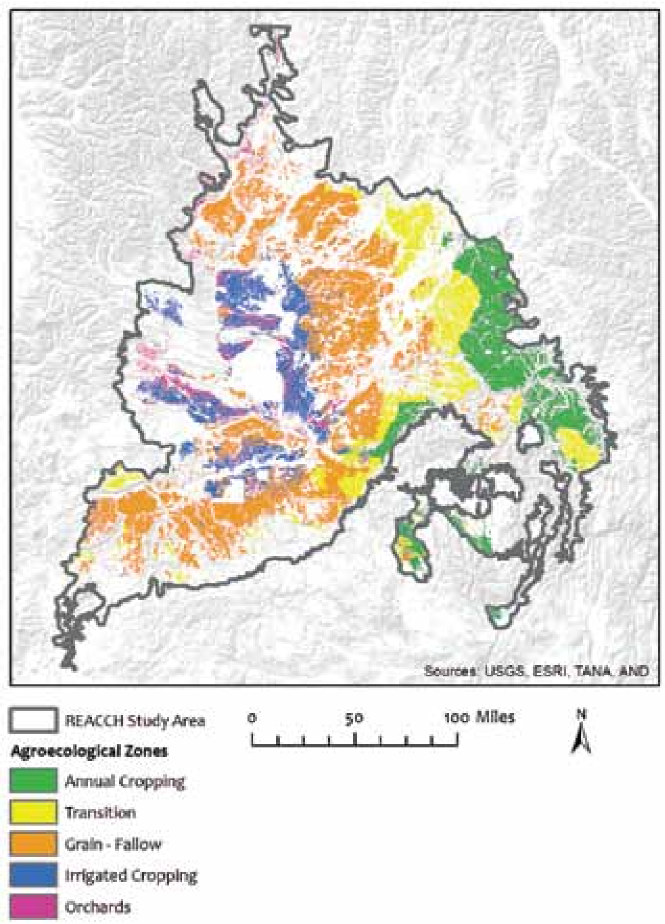

Figure 1. *Dynamic REACCH agroecological zones as defined by land use where Zone 1 = dryland annual cropping; Zone 2 = transition; Zone 3 = grain/fallow; Zone 4 = irrigated winter wheat.*

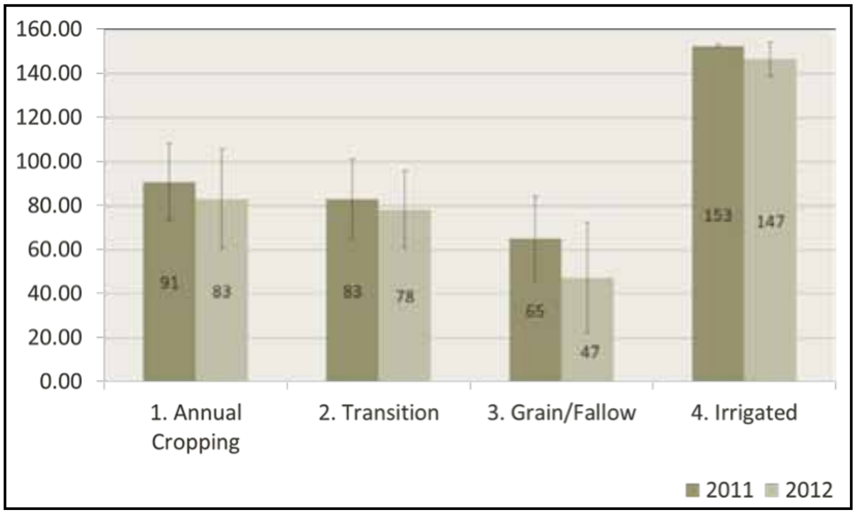

Figure 2. *Average winter wheat yield (bu/acre) by agroecological zone (2011–2012).*

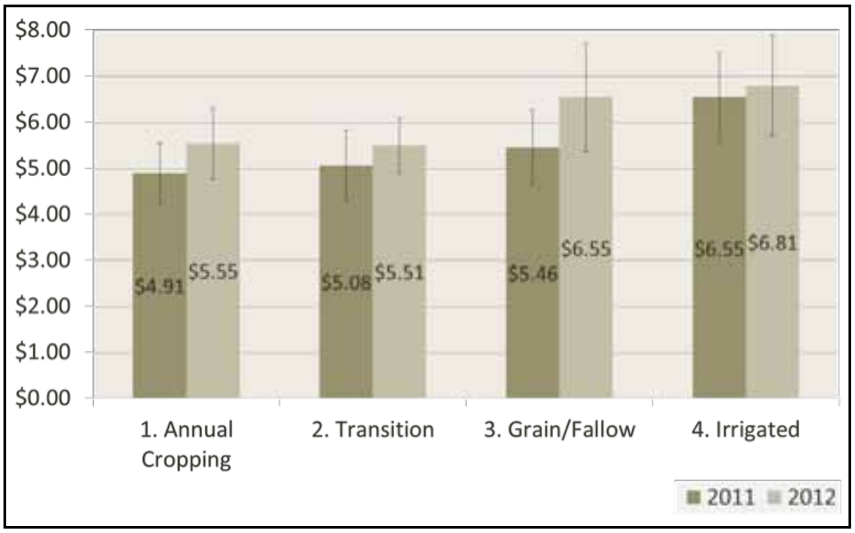

Figure 3. *Average winter wheat cost ($/bu) by agroecological zone (2011–2012).*

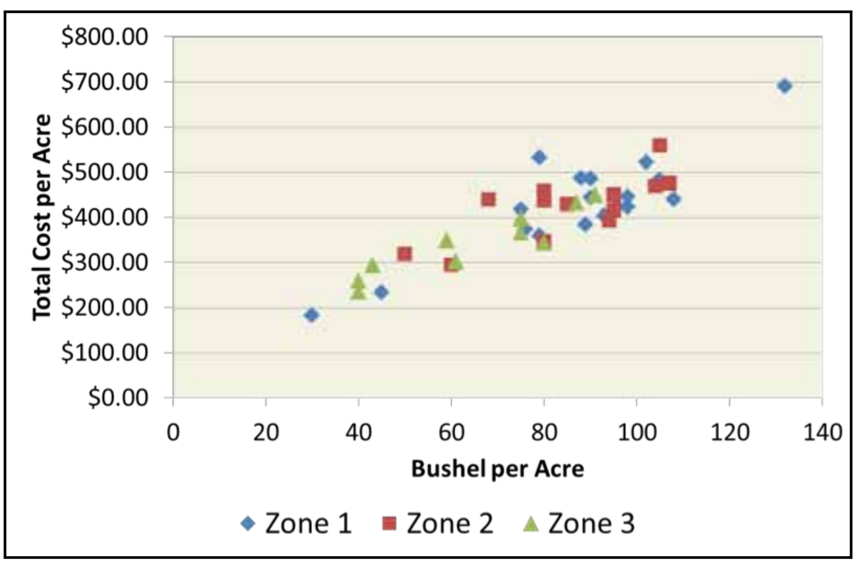

Figure 4. *Total cost ($/bu) and average winter wheat yield (bu/acre) by agroecological zone (2011–2012).*

currently participating in the longitudinal survey. Average acreage for these two farms was just over 2,500 acres. At 149 bu/acre, average winter wheat yield for 2011 and 2012 is highest under irrigated production (Figure 2). Nonetheless, profitability is lowest, at $69/acre in 2011, due to the higher costs associated with irrigated production.

Each of the longitudinal survey growers provided detailed economic data on their machinery, field operations, and input usage so that we could accurately calculate their per-bushel costs. Costs per bushel increased as zone numbers increased. Zone 1, annual cropping, had the lowest production costs—$4.91/bu in 2011 and $5.55/bu in 2012 (Figure 3). Higher than average yields were experienced across all dryland zones in 2011, which accounts for the reduction in per-bushel costs. Zone 4, the irrigated zone, had the highest production costs, at $6.81 per bushel in 2012, due to additional expenses associated with irrigation as well as higher input levels for this high-yielding area. Zone 3, the least productive dryland zone, also had higher per-bushel production costs than Zones 1 and 2, at $5.46/bu in 2011 and $6.55/bu in 2012, due to its lower productivity. High-yielding scenarios reduce costs per bushel for fixed costs such as land rent and machinery ownership, but they may increase other costs, such as fertilizer and fuel requirements.

These growers serve as a critical source of primary data on this project. Documenting interregional differences will help others understand the complexity of farming operations as well as the unique characteristics of different cropping systems in place across this varied region. However, each grower has different resources, in terms of land, capital, management, and machinery, and no two growers farm alike. This individual variation across zones is illustrated in Figure 4, which compares total costs per acre with productivity (bu/acre) by zone for each grower. While there is a general trend of increasing costs as productivity increases, there is a surprising amount of diversity among growers in each zone. Given the average values presented in Figures 1 and 2, the point that there is a large variation among individual growers should be underscored.

Cereal leaf beetle under projected Pacific Northwest climates

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Climate change can influence the range and severity of pests, both directly as these insects respond to climatic factors, and indirectly through effects on competitors and natural enemies. This is a global issue, but one that needs to be considered as part of any climate and agricultural research for our region. A recent U.S. Department of Agriculture (USDA) report lists 20 pests affecting U.S. crops that have the potential for increased pressure with climate change. One of these is the cereal leaf beetle (CLB), *Oulema melanopus* (Figure 1a, b), a pest of cereal grains, grass forage/seed crops, and other grass-host species in the Pacific Northwest. This REACCH study is using down-scaled climate models to examine the historical and projected suitability of future climates for CLB as a pest of wheat in the Pacific Northwest.

IMPACT

The cereal leaf beetle is a relatively new pest in our region and is being held in check by classical biological control. Projections indicate that although climatic conditions favorable to the cereal leaf beetle, and its potential impact as a pest, should increase, biological control will continue to be effective.

CLB is an invader from Europe that spread westward after first detection in Michigan in 1962. It appeared in the REACCH region in the late 1990s and is now well established, based on sampling carried out by REACCH entomologists (Figure 2). It has caused yield losses in spring wheat of 25% in Washington and 20% in Oregon, but seems to be held in check by the successful introduction of a parasitic wasp, *Tetrastichus julis* (Figure 1c) by Washington State University and USDA Animal and Plant Health Inspection Service (APHIS) scientists. However, the severity of this pest and the effectiveness of biological control could be altered under future climates. For example, climate models conducted by Canadian scientists indicate that CLB will affect more acreage and have higher populations in western provinces by the mid-21st century.

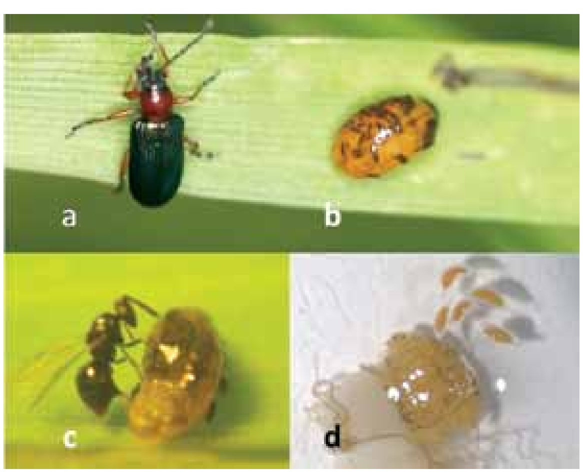


Figure 1. *The cereal leaf beetle and its parasitoid: (a) adult, (b) larva, (c) parasitoid (T. julis), (d) parasitoid larvae dissected from an affected cereal leaf beetle. Photos a-c by Nate Foote, d by Ying Wu.*

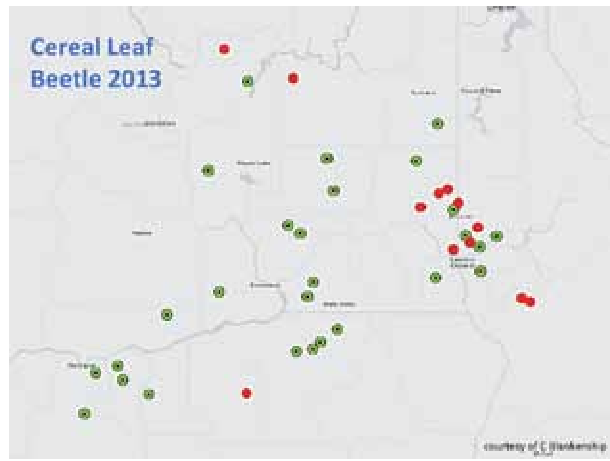


Figure 2. *Cereal leaf beetle distribution in the REACCH region, 2013. Green marker = injury; adult beetles or larvae were detected at this sample location. Red = no evidence of the presence of cereal leaf beetle. Abundance of the beetle was low at all locations where it was detected.*

To assess future risks from CLB, we are conducting a two-stage modeling project. In the first stage, we use projected climate data and published data about the environmental conditions suitable for CLB to map projected changes in potential severity of this pest by the mid-21st century. To do this, fine-scaled climate projections are estimated daily and are used to create a "suitability index" (SI) based on historical climate data and projected climates. The index ranges from zero to 30. We then subtract historical indices from future ones to generate a projected change in this index. In general, this index is projected to stay the same or increase (Figure 3). Indeed, in some areas (the Willamette Valley and near Walla Walla), this index increases considerably more than in others. Based on these projections, CLB could become more difficult to manage under future climates in the Pacific Northwest.

On the other hand, our projections also need to consider biological control by the parasitic wasp. The second stage of our project is based on published data on the life cycles of the wasp and the beetle and how these respond to climate. Our models so far indicate that the overlap between wasp attack and vulnerable larval stages of the beetle will stay the same or increase by the mid-21st century across most of the REACCH region (Figure

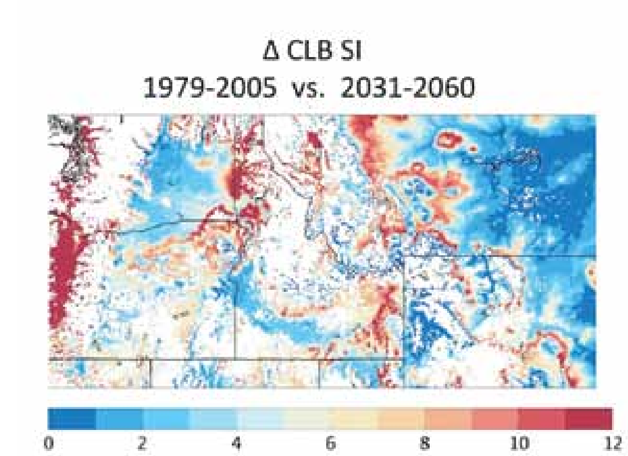


Figure 3. *Map of the change in the Suitability Index (SI) for cereal leaf beetle under projected climates by the mid-21st century in the Northwest. Warmer colors indicate an increase in suitability.*

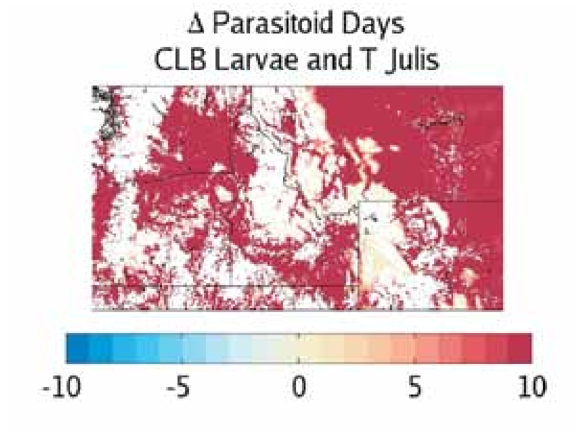


Figure 4. *Map of the change in overlap (number of days) between cereal leaf beetle larval stages and activity of both generations of the parasitic wasp,* T. julis*, in the mid-21st century. Throughout most of the region, overlap is projected to increase, suggesting that biological control by this wasp should be at least as effective as it is today.*

4). This result indicates that the successful biological control program for CLB should continue to be effective across most of our region. Nonetheless, in some restricted areas, increases in CLB SI, coupled with no increase in the potential for biological control, could lead to hot spots where CLB will be more difficult to manage.

These models can be refined or augmented by information acquired through experiments. Greenhouse experiments underway within REACCH are determining whether injury caused by CLB is more severe on drought-stressed wheat, and whether drought conditions alter the growth and development of the beetle or the capacity of the parasitic wasp to attack. These complex interactions involving all three components of the system (crop, pest, and biological control agent) can work together to determine the net effects of climate change on pest management. As results are acquired, they will be incorporated into more comprehensive projections for CLB as a pest of wheat into the 21st century.

Cereal in early summer on the Palouse. Photo by Brad Stokes.

Modeling aphid population dynamics

Thomas Seth Davis (thomasd@uidaho.edu) UI, John Abatzoglou UI, Nilsa Bosque-Perez UI, and Sanford Eigenbrode UI

Under ongoing climate change, it is becoming increasingly important to understand drivers of pest insect populations in cereal grain systems. The prediction of insect population trends is a complex task and often requires a dedicated approach to data collection. Using information collected over a multi-decadal time period and across a regional spatial extent, researchers at the University of Idaho and Washington State University have developed predictive models of cereal aphid populations for three common pest species (bird cherry-oat aphid, *Rhopalosiphum padi* (Figure 1); rose-grass aphid, *Metopolophium dirhodum*; and the Russian wheat aphid, *Diuraphis noxia*) that pose a significant management concern to agriculturalists. In addition to their direct negative effects on plant growth, these insects can also carry viruses such as barley yellow dwarf virus that substantially reduce cereal yields.

Figure 1. *The bird cherry-oat aphid,* Rhopalosiphum padi, *on wheat leaves. These aphids transmit damaging viruses and can severely reduce wheat yields when populations are high. Photo by Brad Stokes.*

IMPACT

Models can be used to predict years when cereal aphid population densities can be expected to reach high or low levels, thus indicating the need for applications of insecticides. Precision chemical application may be achieved by employing our models to estimate insect abundances as part of an overall integrated pest management strategy. Over the long term, this will contribute to reduced up-front costs for growers, as well as enhance the environmental sustainability of cereal grain production.

In the early 1980s, a network of 28 trapping locations was established throughout the Pacific and inland Northwest in cereal grain production regions (Figure 2). Each location was outfitted with a “suction trap”; a tower designed specifically to sample populations of migrating aerial insects (Figure 3). For 20 years, traps were operated by University scientists, and insect captures were identified and catalogued on a weekly basis. In addition, the application of surface-corrected climate models has allowed us to link these trap capture records with weather patterns during the operational dates of the trapping network. This information has allowed us to investigate how both intrinsic, population-driven factors and extrinsic climate effects influence year-to-year variation in aphid densities across the northwestern United States.

The important findings of our work were threefold: (1) Populations of each cereal aphid species are apparently strongly regulated by strong feedbacks: as aphid densities in a given year rise, aphid densities in the following year are likely to be considerably lower, and vice versa. (2) A combination of climate variables and population models were used to construct predictive models of inter-annual aphid density and population growth rate, with strong models developed for population growth rate in the case of

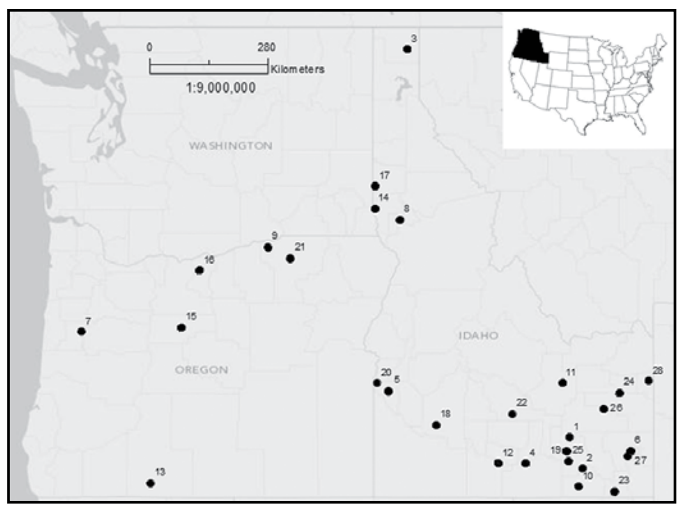


Figure 2. *Suction trap locations used in this study. The inset (upper right corner) highlights the geographic region encompassed by our study within the continental United States. Scale and distance bar is shown in the upper left corner. Locations correspond to (1) Aberdeen; (2) Arbon Valley; (3) Bonners Ferry; (4) Burley; (5) Caldwell; (6) Conda; (7) Corvallis; (8) Craigmont; (9) Hermiston; (10) Holbrook; (11) INEL; (12) Kimberly; (13) Klamath Falls; (14) Lewiston; (15) Madras; (16) Moro; (17) Moscow; (18) Mountain Home; (19) Neely; (20) Parma; (21) Pendleton; (22) Picabo; (23) Preston; (24) Ririe; (25) Rockland; (26) Shelley; (27) Soda Springs; (28) Tetonia.*

all three species. (3) There was no clear biogeographic pattern of aphid density, suggesting that all locations surveyed are equivalent in terms of year-to-year aphid abundance.

These findings suggest that the processes regulating aphid population dynamics tend to occur over very large spatial scales. (The extent of our study region was more than 250,000 km, roughly the size of the United Kingdom.) However, aphid dynamics were not uniformly predicted by climatic variation at this scale; rather, certain species were highly responsive to climate, and others were not. Under projected warming, we predict that *D. noxia* will become less prevalent in the region, whereas *M. dirhodum* abundance is likely to increase if annual precipitation rises. Irrespective of climate variability, we expect that *R. padi* is likely to persist as a pest of cereal grains in the northwestern United States.

Figure 3. *A suction trap located near Moscow, Idaho. Photo by Brad Stokes.*

Rhizoctonia bare patch and root rot: Distribution and management

Patricia Okubara USDA-ARS, Kurt Schroeder WSU, and Timothy Paulitz (paulitz@wsu.edu) USDA-ARS

Rhizoctonia is a fungus that attacks the roots of wheat and barley, causing root rot and subsequent economic loss for producers. In the dryland wheat cropping area of the inland Pacific Northwest, there are two primary species—*Rhizoctonia solani* AG-8 and *Rhizoctonia oryzae* (also known as *Waitea circinata*). Young seedlings are especially susceptible to these root-infecting fungi. We find more damage in spring-planted wheat, because the disease is more severe under the cool, wet soil conditions that are often present in the spring.

IMPACT

Bare patch disease caused by *Rhizoctonia* fungus increases during the transition from conventional tillage to no-till, but eventually declines to background levels. Higher levels are seen in lower precipitation areas, and lower populations in higher precipitation areas. Growers have both cultural and chemical tools available to combat this disease. Treatment and planting time intervals are critical for bare patch disease control. Seed treatments do not always result in increased yields. As part of the REACCH project, we hope to develop models that will predict the distribution of these and other soilborne pathogens under future climate scenarios.

Because the roots are destroyed, plants are unable to take up sufficient water and nutrients. They become more prone to drought stress, and yield is reduced. *Rhizoctonia* can cause stunting of plants, resulting in uneven heights across a field. The first seedling roots are rotted, leaving the tips a brown color. Further down the root, areas are rotted away, leaving a pinched-off appearance, with the center of the root intact. These are the typical symptoms seen in the higher precipitation areas of 18 inches or more in eastern Washington and northern Idaho, where annual cropping systems are common.

However, another symptom, called bare patch, is seen in certain areas of the state, especially in the Dayton-Walla Walla and Ritzville-Connell areas, where no-till or other tillage reduction practices are used. The field may be covered with large patches several yards across, where the wheat or barley is severely stunted or absent. Essentially no yield comes from these patches (Figure 1). This disease increases during the transition from conventional to no-till. In some cases, the disease may decline over a period of many years, and we are attempting to explain how microbial communities naturally suppress or combat the disease.

With funding from the Washington Grain Commission, we developed molecular techniques that allow us to quantify the pathogen in the soil to answer the question, Where and how much fungus is present? These techniques can detect and quantify specific pathogens because each has a unique DNA fingerprint. Over the course of 3 years, we sampled grower fields and Washington State University variety testing sites throughout the state of Washington. As part of the REACCH project, we also analyzed how these populations are related to the climatic differences across the state, primarily based on precipitation and temperature.

What have we discovered about the distribution of this pathogen and disease? With *Rhizoctonia solani* AG-8, we tend to find higher populations in the lower precipitation areas, especially those having sandier soils. Figure 2 shows a map of these sampling sites. The purple and star symbols show sites with higher levels of DNA in the soil, compared to the yellow and orange sites. The populations tend to be lower in the Palouse of eastern Washington, where we typically do not see bare patch, but find uneven stands and root rot.

On the other hand, *Rhizoctonia oryzae* is more evenly distributed across eastern Washington (Figure 3). High and low DNA sites are evenly distributed across the region. When we look at the correlations between populations of *R. solani* AG-8 and precipitation, we find a negative relationship; the higher populations are seen in lower precipitation areas, and lower populations in higher precipitation areas (Figure 4). The DNA values are on a log scale, so the sites in the low (200 mm) precipitation areas may have 10 to 100 times more DNA than sites in the 600 mm zones. As part of the REACCH project, we hope to develop models that would predict the distribution of these and other soilborne pathogens under future climate scenarios.

How can growers manage this disease? They have two sets of tools in the toolbox—cultural and chemical. For cultural control, reduction of the green bridge is essential, especially for spring wheat. *Rhizoctonia* and other soilborne pathogens also grow on

Figure 1. *Rhizoctonia bare patches in spring wheat, Ritzville, Washington. Photo by Timothy Paulitz.*

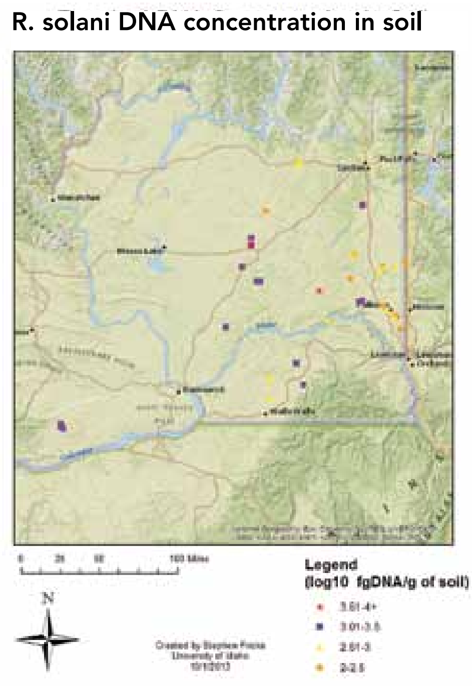


Figure 2. *Map showing concentration of DNA of* Rhizoctonia solani *AG-8 in soils across eastern Washington (grower fields and variety testing sites), sampled in 2006–2008.*

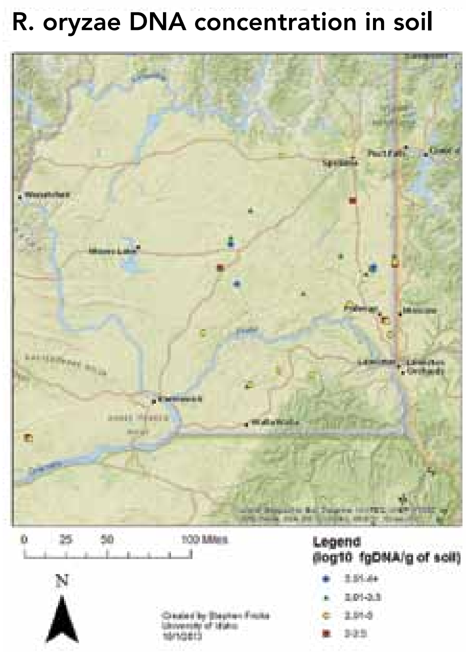


Figure 3. *Map showing concentration of DNA of* Rhizoctonia oryzae *in soils across eastern Washington (grower fields and variety testing sites), sampled in 2006–2008.*

the roots of grassy weeds and volunteers. When these weeds are treated with glyphosate prior to planting, the fungus can grow on the dying weeds and build up to a high level. This is because the fungus can grow on both living and dead tissue. If the crop is planted into these dying plants, the fungus will bridge over to the young wheat or barley seedlings; hence the name "green bridge." But if a sufficient time is allowed for the weeds to die before planting, the pathogen population cannot survive well, and damage is reduced. This interval should be at least 2 weeks, preferably 3 weeks.

The second tool is seed treatments with chemicals such as Dividend, Raxil, and newer classes of SDIs (succinate dehydrogenase inhibitors) such as Vibrance Extreme (sedaxane + difeneconozole + mefanoxam). Studies have shown that seed treatments will improve the health of young seedlings, although treatments do not always result in statistical increases in yield.

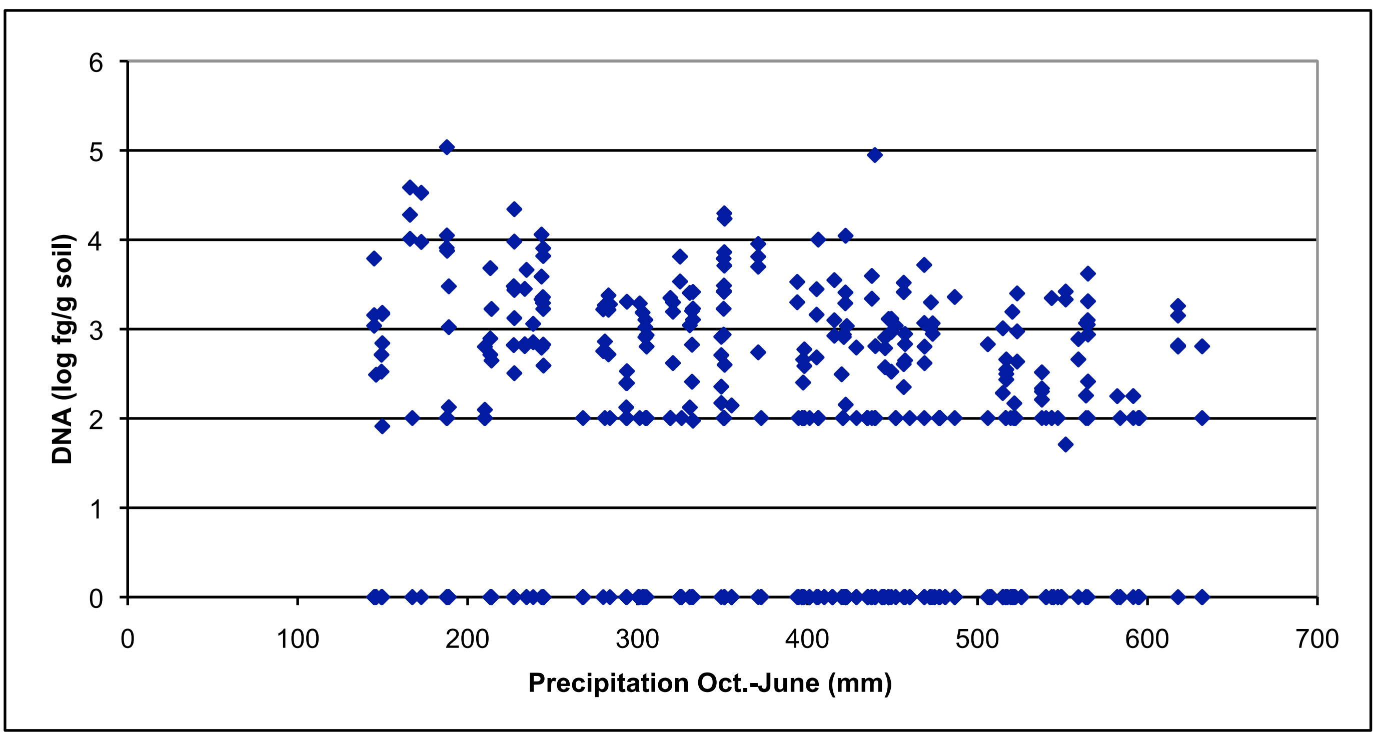


Figure 4. *Relationship between DNA concentration of* Rhizoctonia solani *AG-8 and cumulative precipitation from October to June. Data pooled from 3 years of sampling in grower fields and variety testing sites.*

Downy brome management under future climate scenarios

Ian Burke (icburke@wsu.edu) WSU, Nevin Lawrence WSU, and John Abatzoglou UI

Growers in the Pacific Northwest (PNW) are likely to see shifts in agroecozones and will need to adapt practices as climate changes. Increasing mean annual temperatures, increasing spring precipitation, and decreasing summer precipitation have been observed in the PNW over the past 50 years. Changes in the PNW climate over the next century are projected to outpace recent trends. To aid in grower adaptation, better knowledge of weed response to climate change is needed.

Bromus tectorum (downy brome) is an invasive winter annual grass species, widespread throughout the winter wheat production regions of the PNW. Physiological development of downy brome occurs earlier in the season than does that of other winter annual grasses. Winter wheat yields can be reduced by up to 90% if downy brome is left uncontrolled, and even moderate infestations can significantly reduce profitability.

IMPACT

Both the projected changes in downy brome development and current distribution of downy brome accessions follow an east-west gradient. Since early-flowering accessions will be better adapted to warmer springs and less severe winters, it is likely that early-flowering accessions will experience a range expansion toward the east as climate changes.

Downy brome is difficult to control through cultural practices, and growers primarily rely on herbicides when conservation tillage is utilized. Multiple independent introduction events of downy brome have resulted in multiple inbred naturalized populations coexisting across landscapes (Figure 1). Selection often favors range expansion of pre-adapted biotypes rather that evolution of novel traits. Many phenotypic traits demonstrate high environmental plasticity; however, flowering time is a relatively stable trait of adaptive significance. The widespread distribution and stable influence of environment on flowering time make downy brome an ideal species for studying the impacts of climate change.

A previously published downy brome development model using cumulative growing degree days (GDD), starting on January 1 and with a base temperature of 0°C, has been used to predict mature seed set. According to the model, plants collected from the PNW set mature seed around 1,000 GDD.

Using this value, 14 climate models that adequately captured the historical characteristics of the PNW climate were downscaled to compare the mean calendar date when 1,000 GDD was reached from 1950 to 2005 to the projected mean calendar date for reaching 1,000 GDD from 2031 to 2060 (Figure 2). Across all models and locations, the calendar date at which 1,000 GDD was reached was projected to occur earlier in the year. This date advanced 10 to 30 days, depending on the model used. When models were averaged, the projected date advanced 15 to 25 days, depending on location. The projected calendar date to reach 1,000 GDD follows an east-west gradient across the projected region in all models. The eastern region of small grain production in the PNW is projected to have the least change, while the western region is projected to have the greatest advance in calendar date needed to reach 1,000 GDD.

Figure 1. *Downy brome variation in the Pacific Northwest. Photo by Nevin Lawrence.*

Downy brome accessions were collected from 95 locations within the winter wheat production region of the PNW. These accessions were brought to seed within greenhouse settings and later transplanted to a field site near Central Ferry, Washington in November 2012 (Figure 3). The field site was visited weekly, and plant development was recorded, along with accumulated GDD beginning January 1. Plant development differed by up to 3 weeks among accessions at the Central Ferry location, which is hypothesized to be the result of differing vernalization requirements to induce flowering.

When the distribution of early- and late-flowering accessions identified in the common garden experiment is plotted across the small grain production regions of the PNW, a strong spatial trend is evident. Early-flowering accessions are predominantly found in central Washington and north-central Oregon, while late-flowering accessions are more commonly located in the Palouse region of eastern Washington and northwestern Idaho. While the distribution of early- and late-flowering biotypes was heavily influenced by east-west orientation, north-south orientation did not significantly contribute to the distribution of accessions.

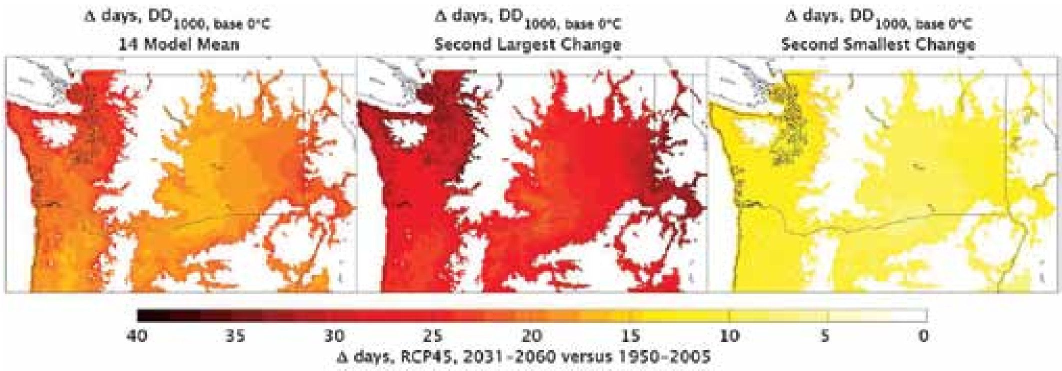
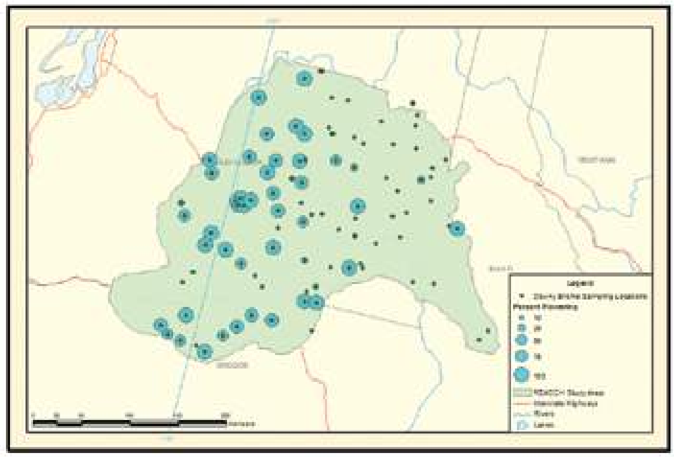


Figure 2. *Projected change in downy brome flowering date (at 1,000 growing degree days) across the Pacific Northwest.*

Both the projected changes in downy brome development and current distribution of downy brome accessions follow an east-west gradient. Those areas that contain late-flowering biotypes are projected to undergo the greatest amount of change in growing degree accumulation. As early-flowering accessions will be better adapted to warmer springs and less severe winters, it is likely that early-flowering accessions will experience a range expansion toward the east as climate changes. With downy brome development projected to advance in time, control inputs will likely need to advance in time as well. Across the high rainfall regions, timely applications are often delayed by spring moisture events. With advancing downy brome development and increasing spring moisture, control may be impacted. Range expansion of downy brome accession currently located in central Washington and Oregon could also result in the movement of herbicide resistance traits from the west to the east as several of the early-flowering accessions have tolerance to selected acetolactate synthase (ALS)-inhibiting herbicides.



Distribution of early and late flowering downy brome accessions in the PNW based on percent flowering at 880 GDD.

Further refinement of the downy brome development model could improve the accuracy and usefulness of future climate projections. Field studies are currently underway to incorporate greater spatial resolution of downy brome phenotypic variation. Additional work is also ongoing to incorporate historic climate changes as a covariate in the spatial analysis of current downy brome accession distribution.

Figure 3. *Downy brome common garden. Photo by Nevin Lawrence.*

Wireworm biology and ecology in Washington cereal crops

David Crowder (dcrowder@wsu.edu) WSU, Aaron Esser WSU, and Ivan Milosavljevic WSU

Wireworms (Figure 1), the subterranean larvae of click beetles, have emerged as significant pests of cereal crops. Our team has joined REACCH to address these pests, their management, and responses to climatic drivers.

Wireworms have proven difficult to manage because they are difficult to sample, and significant damage can be done to crop fields before wireworms are identified and management strategies are implemented. When wireworm densities are high, damage can reach extreme levels, including the loss of entire plots or fields. Unfortunately, producers are faced with the daunting challenge of contending with this emergent pest without the fundamental knowledge to develop new management tools. Our objectives are therefore to examine the ecology of wireworms across variable landscapes and climatic regions in the Pacific Northwest. Our research focuses on the following objectives: (1) determine the distribution of wireworm species in cereal crops; (2) develop a predictive model for wireworms; and (3) deliver information to growers.

IMPACT

Understanding climatic/land use impacts on wireworms can improve their management. This project is developing models to predict wireworm risk based on surveys and climate data. Producer surveys conducted by other teams within REACCH will help ensure models and tools are useful.

In 2013, we conducted a large-scale survey examining the distribution and ecology of wireworms in spring and winter wheat fields in the Pacific Northwest. Surveys were conducted by placing 10 baits in each of 60 cereal fields (40 spring wheat, 20 winter wheat). From these surveys, a total of 1,536 wireworm individuals were collected across samples taken from 60 field locations in 19 counties (Table 1). Three species, *Limonius infuscatus*, *L. californicus*, and *Ctenicera* sp., represented approximately 95% of wireworms collected (Table 1). The dominant species detected varied across counties, suggesting that landscapes and climate may play a role in species distribution.

With the aim of developing a predictive wireworm model, we are expanding these surveys in 2014 to continue to explore wireworm distribution across the REACCH domain. We will use these data to develop a model to allow growers to accurately assess their wireworm risk before planting, so that appropriate treatments can be applied or high-risk sites avoided. Lists of factors predictive

Table 1. *Numbers of wireworms collected from spring wheat fields in Washington.*

State	County	*Limonius infuscatus*	*Limonius californicus*	*Ctenicera* spp.	Other spp.
ID	Benewah	14	—	—	—
ID	Kootenai	—	26	—	—
ID	Latah	—	49	—	—
ID	Nez Perce	—	—	—	68
OR	Morrow	—	—	20	—
OR	Umatilla	54	14	—	—
WA	Adams	—	—	85	—
WA	Asotin	41	—	—	—
WA	Benton	—	—	5	—
WA	Columbia	44	5	—	2
WA	Douglas	—	8	3	—
WA	Franklin	—	1	21	—
WA	Garfield	172	1	—	—
WA	Grant	—	24	85	—
WA	Klickitat	—	—	49	—
WA	Lincoln	243	42	—	—
WA	Spokane	133	27	—	5
WA	Walla Walla	—	23	—	—
WA	Whitman	268	—	—	4
	Total (%)	969 (63%)	220 (14%)	268 (17%)	79 (5%)

Figure 1. *Larval wireworm sampled from a Washington wheat field. Photo by Ivan Milosavljevic.*

of wireworm risk are available, but these often seem to be based on educated guesses rather than quantitative data. In the coming years, we will use our sampling data to develop a quantitative listing of factors that affect wireworm densities.

Data on wireworm densities are being used to develop multiple regression models incorporating data on 15 environmental and operational factors proposed to affect wireworms (explanatory variables). These data will be obtained from the following sources:

- Temperature and precipitation—from agricultural weather stations (agweathernet.com)
- Soil temperature—from hobo data loggers planted in the soil next to baits (These dataloggers record temperatures every 15 minutes.)
- Land use—from the U.S. Department of Agriculture Cropland Datalayers program, which provides data on land use at a 30 x 30 m grain throughout the United States (These maps can be visualized in GIS, and land around focal fields can easily be quantified.)
- Soil properties—from soil samples taken at each bait location
- Management practices—obtained directly from growers in each sampled field

Through these analyses we will determine how grower practices and climatic variables influence wireworm risk.

Our team gave three presentations about wireworms to growers at field days. We also made contact with over 40 different growers, working directly on their farms to sample wireworms. Our network has expanded since we joined the REACCH project in 2012, and we hope to continue to expand the scope of our outreach in future years.

Figure 2. *Larval wireworm. Photo by Ivan Milosavljevic.*

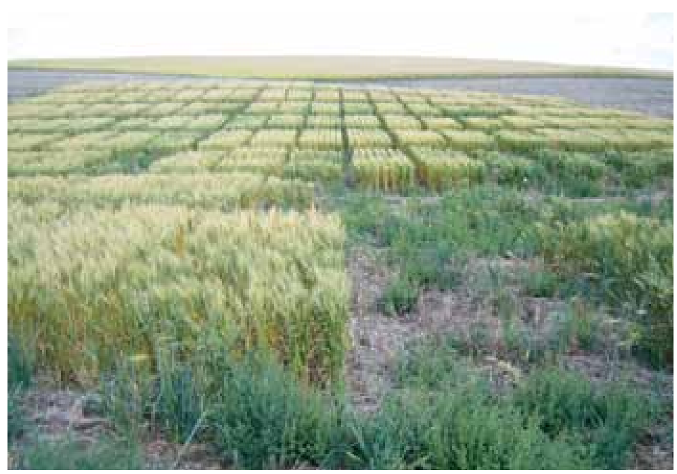


Figure 3. *Large-scale field trials for wheat yield in areas with wireworm. Photo by Ivan Milosavljevic.*

Earthworm density and activity across three agroecological zones

Chelsea Walsh (wals9279@vandals.uidaho.edu) UI, Heath Hewitt UI, and Jodi Johnson-Maynard UI

Greenhouse experiments have shown that earthworms have the potential to increase crop yields by improving nutrient cycling, water infiltration, and soil structure. Many of these experiments, however, use densities of earthworms that are much greater than those found in agricultural fields. In addition, earthworm experiments are often carried out under ideal soil temperature and moisture levels, promoting constant earthworm activity.

In reality, soils sometimes experience rapid drying and warming during the growing season, which may result in earthworms entering a hibernation-like state known as aestivation. Aestivation allows earthworms to survive arid conditions by reducing surface area and stopping metabolic activity. Aestivating earthworms cease feeding, create a small chamber (Figure 1), and remain coiled and inactive until soil conditions are favorable.

The onset and length of earthworm inactivity in the inland Pacific Northwest, which experiences significant dry-down and warming during the late spring and summer months, are unknown, and aestivation may moderate expected positive influences of earthworm activity on soil processes and plant growth. This study compares earthworm densities and aestivation between the spring and summer in three agroclimatic zones of the wheat production region to provide an initial characterization of aestivation cycles in dryland wheat production systems within the inland Pacific Northwest.

IMPACT

The ability to curl up in a ball and aestivate (enter a hibernation-type state) allows earthworms to survive temporary periods of warm, dry conditions, but may limit their impact on soil properties and plant growth. Earthworm density and biomass seem to be more related to soil moisture content than to temperature.

Figure 1. *An earthworm found aestivating in the summer of 2013. The coiled worm is approximately 1.5 cm in diameter. Photo by Chelsea Walsh.*

Figure 2. *A REACCH summer intern and staff member sample a field for earthworms. Photo by Chelsea Walsh.*

In the spring of 2012 and 2013, 40 sites across the region were sampled for earthworms (Figure 2). In June and July of 2013, the 20 sites where earthworms had been detected in the spring were resampled. Earthworm density (worms per square meter), volumetric soil moisture content, soil temperature, and the presence of aestivating earthworms were recorded. Earthworms were collected from two 25 x 25 x 50 cm pits in each field, using hand sorting and sifting. Each field sampled was placed into one of three agroclimatic zones (annual, transition, or crop-fallow) based on the proportion of crop to fallow and the presence of irrigation around each pixel of the CropLand data layer.

As anticipated, average soil moisture in the top 30 cm of soil decreased in all zones between the two sampling periods, while average soil temperature increased across all zones. Across zones, soil moisture decreased an average of 10.4%, and soil temperature increased an average of 3.4°C at sites where earthworms had been found. Earthworm density ranged from 8 to 190 individuals m^{-2} (average 66.3) in the spring and from 0 to 45.8 individuals m^{-2} (average 9.9) in the summer. The decrease in earthworms is most likely a combination of mortality and movement by earthworms deeper into the soil, where soil temperatures are lower.

In the spring of 2013, aestivating earthworms were found at only 3 of the 20 sites. These sites had an average soil moisture of 21% (compared to an average of 27% for all sites in the spring).

Figure 3. *The invasive earthworm* Aporrectodea trapezoides *is the most common species in agricultural fields of this region. Photo by Chelsea Walsh.*

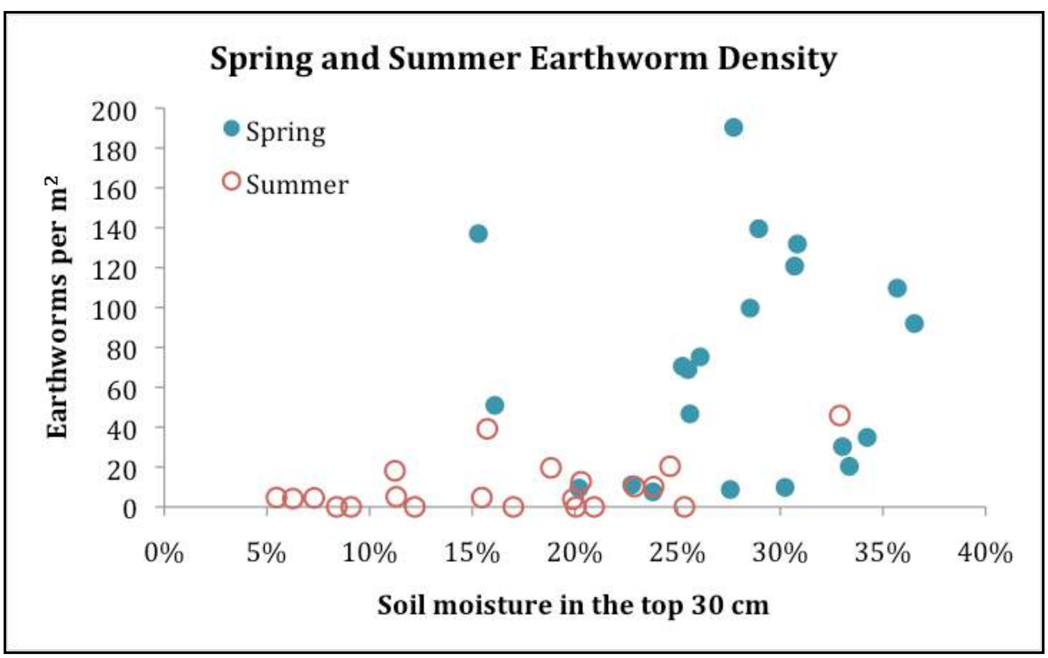
Finding aestivating earthworms in spring was unexpected. In addition, all aestivating earthworms were in the transition zone, which generally receives greater precipitation than does the fallow zone. These results indicate that field-level variability may significantly influence activity periods, even within a climatic zone. In addition to climate, other factors such as soil organic matter, bulk density and management practices likely play a role in determining earthworm density and activity.

In the summer, earthworms were either aestivating or not present at 8 of the 20 sites, with both aestivating and active earthworms present in all three zones. Summer data suggest that earthworms may be able to maintain activity at soil moisture levels of as low as 14 to 19%.

Earthworm density and biomass seem to be more related to soil moisture content than to temperature (Figure 4). Greater sensitivity to soil moisture is consistent with the observation that earthworms tolerate higher temperatures when soil moisture levels are also high. It is important to recognize, however, that soil moisture and temperature tend to change in similar patterns, and that both properties impact earthworm survival.

While the aestivation data presented here are preliminary in nature, they do suggest that patterns of aestivation may be difficult to interpret at the regional scale. The ecological significance of aestivation on soil properties and plant growth in interior Pacific Northwest agroecosystems is unknown and will be the topic of future greenhouse and field studies.

Figure 4. *Relationship between earthworm density and soil moisture at the time of sampling across zones. Earthworm densities were generally higher at higher soil moisture levels, with much greater densities occurring in spring.*



N_2O and CO_2 production in wheat-based cropping systems

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Rainfall, irrigation, and soil nitrogen (N) fertilization are factors that drive emissions of the highly potent greenhouse gas nitrous oxide (N_2O), a major contributor to climate change from agriculture. Changing climate could promote shifts of agroecozones (AEZs) due to increased temperatures, as well as expansion of irrigated agriculture and increased irrigation requirements. An accurate assessment of N_2O and carbon dioxide (CO_2) emissions in irrigation scenarios is required for predicting the effects of changes in agricultural management practices on global climate change.

IMPACT

Soil nitrogen fertilization leads to production of carbon dioxide (CO_2) and nitrous oxide (N_2O), greenhouse gases that contribute to global climate change. This study increases our understanding of the scale of these emissions in dryland and irrigated systems under conventional tillage and no-tillage. The project is designed to develop better greenhouse gas predictions in order to improve nitrogen fertilization and irrigation strategies to reduce greenhouse gas emissions.

No-till management is a conservation practice that can sequester soil carbon, preserve soil moisture, and reduce erosion. Its effects on greenhouse gas emissions are less well known. Therefore, we conducted a study on greenhouse gas emissions (CO_2 and N_2O) in response to water and N additions on long-term inland Pacific Northwest research sites (Pendleton, Oregon; Moro, Oregon; and Kambitsch Farm, Idaho). Cropping systems were conventional tillage (CT) and no-tillage (NT) dryland wheat. A more recently established irrigated site (Prosser, Washington) was also included.

We implemented the system of Li-Cor 8100A automatic chambers coupled with LGR 23r N_2O analyzer for continuous monitoring of CO_2 and N_2O emissions in a short-term micro-plot study with the following treatments: (1) no water or fertilizer, (2) water added to 80% water-filled pore space and amended with 150 kg NH_4NO_3-N ha^{-1}, (3) water added to 80% water-filled pore space, but no fertilizer. Application of N and water took place at 9:00 a.m., and the measurements continued from that time until 7:00 a.m. the following day, for a total of 22 hours (Figure 1). The study was conducted in July 2013, when greenhouse gas response to applied N and water would be expected to be maximal.

In the dryland wheat system scenario, N_2O peaks were higher for water plus N treatments than for water only treatments (Figure 2). Both water plus N and water only treatments had higher N_2O emissions than did the no water treatments. CT treatments resulted in higher levels of N_2O than did NT treatments.

Figure 1. *Dr. Kirill Kostyanovsky applies water and nitrogen treatments to no-till winter wheat stubble. Automated static chambers monitor subsequent greenhouse gas emissions on micro-plots. Photo by Dave Huggins.*

Significantly, N_2O emissions from water plus N NT treatments were less than those from water only CT treatments.

Emissions of CO_2 tended to increase in the water plus N treatments for both CT and NT, compared to water only NT treatments during the first several hours of the study. All water plus N and water only treatments had higher CO_2 emissions than treatments without water added.

The total losses of N to N_2O emissions were 0.02% of the total N applied under CT, compared to 0.017% from NT plots with water plus N during the first day of measurement. With water additions only, an equivalent of 0.017% N was lost from CT plots, and an equivalent of 0.010% N was lost from NT plots. Emissions of N_2O from the plots with no water or N added were negligible.

The irrigated wheat system produced higher N_2O emissions for both N plus water and water only treatments than for the no water treatments. Water plus N treatments resulted in higher N_2O peaks than water only treatments (Figure 2). CT treatments resulted in N_2O emissions 30 to 40% higher than NT treatments.

Emissions of CO_2 were increased in the water plus N treatments and water only treatments compared to the treatments without water added during several initial hours of the study. Water plus N CT treatments also had higher CO_2 emissions than did NT treatments during several initial hours and then decreased to the level of CO_2 emissions from treatments with no water added.

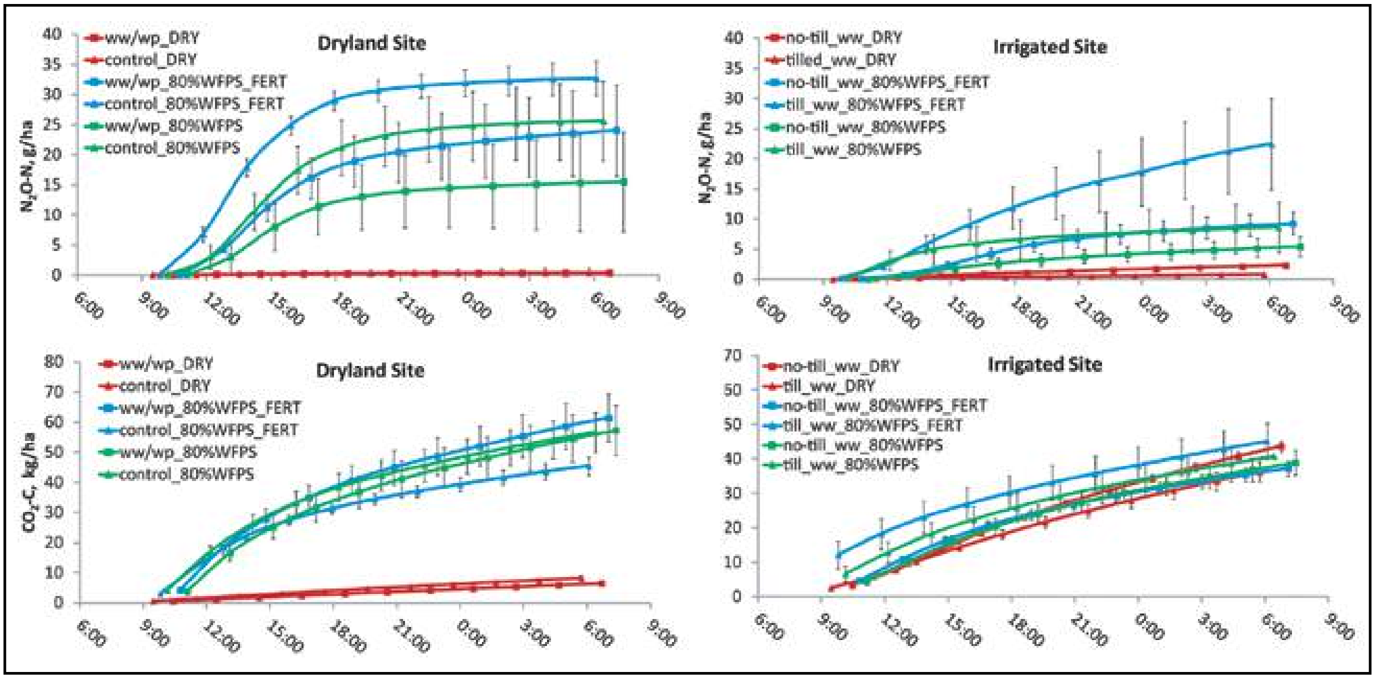

Figure 2. *Cumulative emissions of N_2O and CO_2 during the first day of measurements. Treatments included water only and water plus nitrogen (150 kg N ha^{-1}) under dryland and irrigated no-tillage and conventional tillage management systems.*

Approximately 0.015% of the total N applied was lost to N_2O emissions under CT compared to 0.006% under NT with water and N additions during the first day of measurement. About 0.006% of the total N applied was lost from the CT with only water addition and an equivalent of 0.004% N from NT with only water additions. Emissions of N_2O from the plots with no water or N added were 0.001% of the total N applied for CT and NT during the first day of measurements.

Overall, emissions of N_2O and CO_2 following additions of water plus N and water only were higher from the dryland sites than from the irrigated site. This shows that initial wetting of soil under dryland conditions results in higher spikes of microbial activity than it does on irrigated sites, leading to higher emissions. Emissions of CO_2 and N_2O were likely stimulated by NH_4NO_3 application, due to increased microbial activity from nitrification and denitrification processes, resulting in increased organic matter decomposition in the semi-saturated soil. The processes were more pronounced in CT than NT plots, likely because higher rates of organic matter decomposition and slower internal soil water drainage lead to higher cumulative N_2O and CO_2 emissions. The study demonstrated the significance of NT for reduction of N_2O emissions during fertilization and irrigation events as compared to CT.

Divided slopes and cross-slope farming on hills in Eastern Washington. Photo by Sylvia Kantor.

Catching carbon on the Palouse

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As the wind sweeps across the wheat fields of eastern Washington, it carries air laden with carbon dioxide (CO_2) down to the crop surface, where daytime photosynthesis pulls the CO_2 from the atmosphere and converts it to the building blocks of roots deep in the soil and the growing vegetation at the surface. At the same time, this biological process steadily breathes or respires some CO_2 back into the atmosphere from the soil and the plants. The balance between carbon uptake during photosynthesis and carbon respiration from soils and vegetation determines whether managed cropland provides a net storage reservoir or sink for carbon from the atmosphere.

IMPACT

The balance between uptake of CO_2 during photosynthesis and release of CO_2 during respiration from soils and vegetation determines whether managed cropland provides a net storage reservoir for carbon from the atmosphere. State-of-the-art eddy covariance flux towers are being used by REACCH scientists to measure the long-term net flux of CO_2 from different cropping systems in our region. Differing CO_2 dynamics in different systems and over time are allowing us to develop a complete description of the carbon budgets from wheat-based cropping systems across our region.

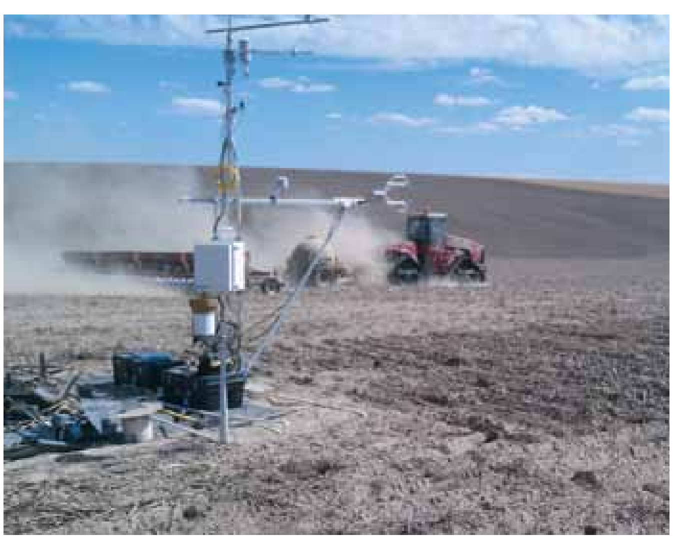
Within the REACCH project, key questions are: Do croplands act as a net sink for carbon from the atmosphere? If so, what is the magnitude of this storage? And, most importantly, can different management approaches increase the amount of carbon stored? To answer these questions, methods are needed that take a long-term look at carbon uptake and loss, and these methods must account for how the hot growing days of summer and the cold, snowy periods in winter affect carbon cycling between the atmosphere and the surface.

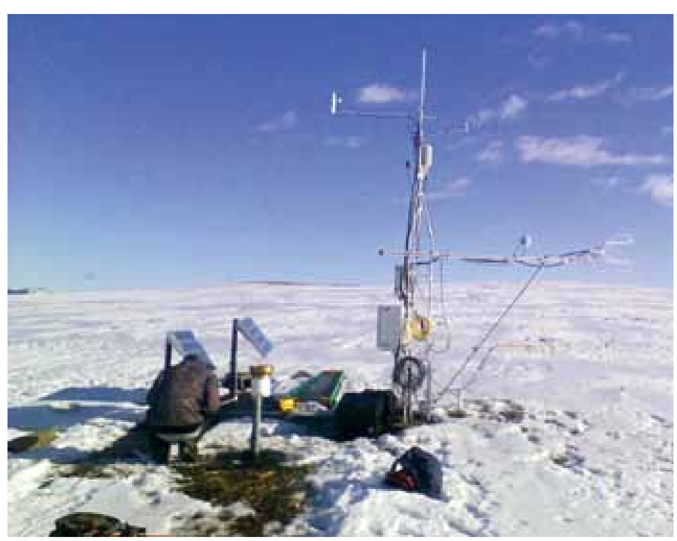
Fortunately, as a result of technological advances over the past several decades, a reliable, sensitive method now exists that can help answer these carbon storage questions. The so-called eddy covariance method relies on ultra-fast measurements of the amount of CO_2 associated with the updrafts and downdrafts from atmospheric eddies embedded in the winds traveling across the Palouse. For REACCH, we have deployed eddy covariance flux towers (Figure 1) at five sites stretching from the irrigated and dryland farming regions in the central basin near Moses Lake and Lind, Washington, to the much wetter rolling hills of the Palouse near Pullman, Washington, and Moscow, Idaho.

At each site, a sensitive sonic anemometer measures the vertical speed of updrafts and downdrafts 10 times a second, while an open path infrared gas analyzer (IRGA) measures the corresponding CO_2 content of these eddy motions. The results are beamed back to our laboratory at Washington State University in Pullman each night. The balance between carbon uptake and loss—called the CO_2 flux—is then calculated for each 30-minute period every day throughout the year. Similar measurements for water vapor fluxes are also collected. Other weather observations include temperature, humidity, the amount of sunlight, and the amount of precipitation, along with data describing soil temperature and moisture conditions. All of the data are combined daily throughout the year.

During the growing period, there is a strong signal of carbon uptake due to photosynthesis, which far outweighs any carbon loss due to respiration. This is shown as the large dip or negative peak in the graphs shown in Figure 2. The pattern is the same at both the dryland wheat/fallow rotation growing area near Lind, Washington, and the annual crop rotation near Pullman, Washington. However, there are distinct differences at these two locations in terms of the timing of the peak uptake (earlier

Figure 1. *The eddy covariance flux tower installations at (below left) Lind, Washington, during tilling operations, and (below right) Cook Agronomy Farm, Washington, in winter. Photos by Patrick O'Keeffe.*





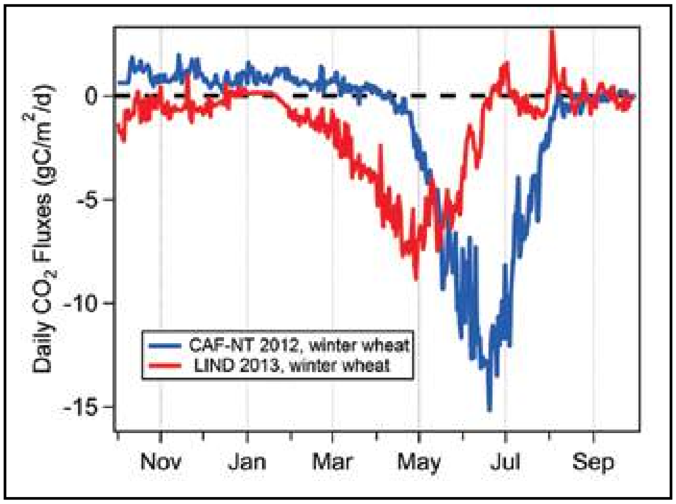


Figure 2. *Daily net carbon flux for the wheat/fallow rotation near Lind, Washington (red line), and the annual crop rotation near Pullman, Washington (blue line). Negative numbers represent the net uptake of carbon from the atmosphere due to photosynthesis.*

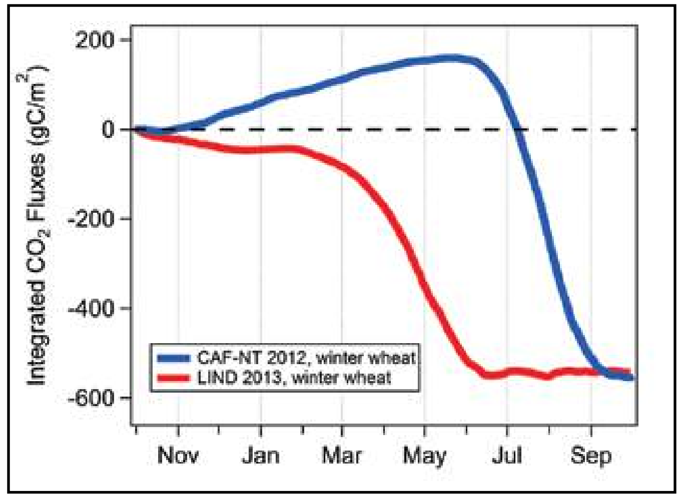


Figure 3. *The net ecosystem exchange (NEE) or net carbon uptake and loss through the 2012 crop year at the Lind wheat/fallow rotation site (red line) and the Pullman annual crop rotation site (blue line). Negative values indicate a net uptake of carbon from the atmosphere.*

at Lind) and the magnitude of the uptake (much larger near Pullman). These differences reflect the differences in productivity of the soil and corresponding crop yields for the two locations.

When the daily balance is summed continuously through the year, the results map the net carbon balance from month to month (Figure 3). Beginning in the fall, with winter wheat planted, net carbon is lost at the Palouse site until the growing season begins in early summer, when the carbon balance shifts sharply to net uptake. The wintertime loss of carbon is likely due to the breakdown of plant residue—the stalks and leaves left on the field after harvest of the previous crop. Near Lind, growers leave the field fallow every other year to conserve water. Since there is no plant residue left on the field to be broken down, we see a slight carbon uptake through the winter as the crop begins to grow. In early spring, carbon uptake increases until it reaches its maximum in June.

To determine the overall amount of carbon sequestered by a given field for a given year, the amount of carbon in the harvested crop must be taken into account. For the Pullman site in the 2012 growing season (Figure 3, blue line), approximately 290 g C/m^2 was exported, or about half of the measured net ecosystem exchange (NEE). This means that about 300 g C/m^2 is stored in the field either as residue at the surface or in the roots below ground.

Overall, the eddy covariance method provides a reliable way to measure the carbon balance for different growing zones and different management approaches. As the REACCH program proceeds, data collected at all of the tower sites will be used with other REACCH components, such as growing chambers and crop models, to develop a complete description of the carbon budget for wheat cropping systems across eastern Washington and Oregon and in northern Idaho.

PhD student Jackie Chi collecting biomass samples at the Cook Agronomy Farm flux site. Photo by Laurel Graves.

Long-term declines in carbon fluxes from the Palouse

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The Palouse region, located in the dryland cropping region of the inland Pacific Northwest, is well known for excessive soil erosion rates. Soil erosion rates have been measured as high as 200 tonnes/ha, with average annual erosion rates often exceeding 45 tonnes/ha during early century periods. A benchmark study in 1978 by the U.S. Department of Agriculture estimated that 40% of the topsoil in the Palouse Basin, as defined by the watershed area upstream of a long-term U.S. Geological Survey (USGS) stream gauging station at Hooper, Washington, had been lost to erosion.

IMPACT

Since the 1960s, mean annual carbon transport has declined nearly 90% at the outlet of the Palouse River Basin, mainly as a result of increased conservation tillage practices. In terms of equivalent CO_2 production, the annual reduction in carbon load is equivalent to the annual carbon emissions from 15,747 cars.

Although soil erosion rates and sediment yield have been widely documented, few studies have focused on quantifying the transport of soil organic carbon at various scales within the basin via erosion and stream sediment transport. Understanding the impact of management and scale on carbon transport will improve our understanding of the effectiveness of future mitigation practices, which aim to increase overall carbon storage in the region. A 2-year study was conducted to quantify long-term declines in soil carbon storage and transport at the outlet, and at various scales within the Palouse Basin, in response to increased adoption of reduced tillage practices in the region.

Five study sites ranging in size from 11 to 647,947 ha were monitored for streamflow in 2012 and 2013. Event-based water samples were analyzed for suspended sediment concentration (SSC), particulate organic carbon (POC), and dissolved organic carbon (DOC). At the field scale, two fields were monitored to detect the influence of management on carbon transport: (1) a 14-ha conventionally tilled farm in Idaho (Figure 1), and (2) an 11-ha catchment within the Washington State University Cook Agronomy Farm that was managed using direct-seed practices. At the watershed scale, soil carbon measurements were made at the USGS Paradise Creek stream gauge location (4,890 ha) and at the Paradise Creek at Darby Road station (2,930 ha) (Figure 2) near Moscow, Idaho. At the basin scale, historic carbon and sediment data were obtained from the USGS stream gauging station on the Palouse River at Hooper, Washington (647,497 ha). These data were compiled with data collected in this study.

Figure 1. *Water quality monitoring at the outlet of the 14-ha Idaho conventional tillage site. Photo by Erin Brooks.*

Total sediment and carbon loads were calculated. In 2012, POC and SSC were highly correlated at each of the stream gauge locations, with the mass fraction of carbon ranging from 0.6% in the Paradise Creek watershed to 1.6% at the Hooper stream gauge location. Figure 3 shows the POC/SSC relationship at the Palouse River gauge at Hooper, Washington for all years. Dissolved organic carbon measurements showed little variability at each station, with an average annual concentration of 6.5 mg/L at the Hooper, Washington stream gauge location.

Total sediment and carbon yields from the Palouse Basin have declined more than two orders of magnitude from 1960 to 2012 (Table 1). Total sediment yield declined from 2 million tonnes/year from the 1962–1971 period to 70,000 tonnes/year during the 2010–2012 period. Similarly, the carbon yield at the Hooper, Washington gauge decreased from 25,000 tonnes/year to 4,400 tonnes/year for the same time periods, respectively. This is more than a 95% decrease in sediment and an 82% reduction in carbon load since the 1960s. The decrease in carbon load has occurred primarily through the reduction in delivery of POC. During the 1960s, only 12% of the total carbon load was delivered in the form of DOC, whereas currently 83% of the total carbon delivered from the basin is transported as DOC.

To provide some perspective, the reduction in carbon load expressed as CO_2 equivalent (i.e., the potential amount of CO_2 that could be released from a given amount of carbon) is equivalent to the CO_2 emitted from 15,736 cars per year. Assuming the reduction in sediment and carbon load has occurred primarily from agricultural lands, then for CO_2 emissions from 111 cars.

While it is clear that carbon and sediment yields are declining in the Palouse Basin, the vast majority of the soil and carbon that is transported by erosion in the region is deposited and stored within the basin. Using a conservative soil erosion estimate of 3.3 tonnes/ha/year, the sediment yield data measured at the Hooper station indicate that less than 5% of all the carbon transport by erosion within the basin will be transported out of the basin. The

Figure 2. *Water quality monitoring station at the outlet of the 2,930-ha Paradise Creek watershed. Photo by Erin Brooks.*

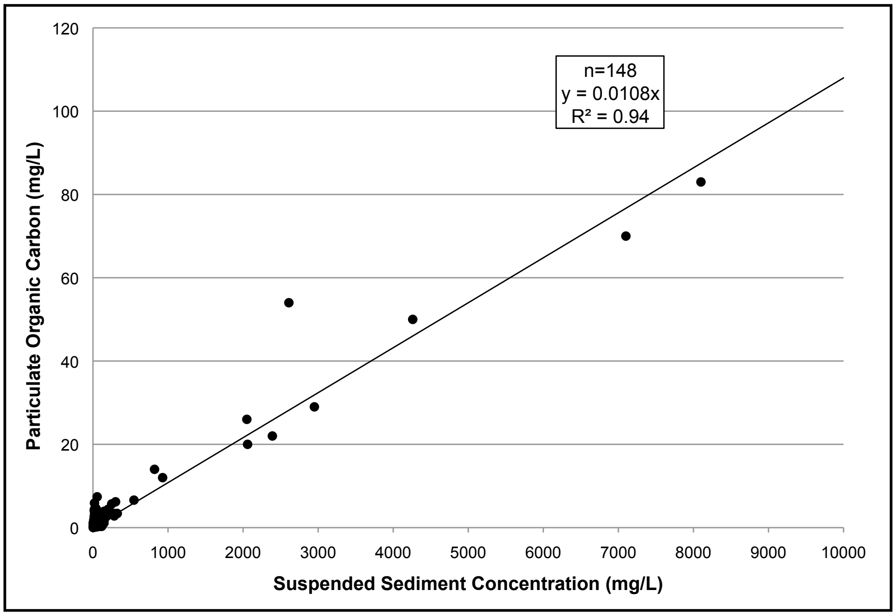

Figure 3. *Relationship between particulate organic carbon and suspended sediment concentrations from historic sampling data at Hooper, Washington (1992–2004).*

remaining 95% is deposited and stored in the landscape.

The dramatic reduction in carbon yield can be largely attributed to the adoption of conservation tillage management practices. As seen in Table 1, despite the similar size catchment, the total carbon delivered from the Cook Farm no-till site is two orders of magnitude smaller than the carbon delivered from the Idaho conventional tillage site.

Overall, the decline in total carbon delivery in the Palouse Basin is impressive. The adoption of soil conservation tillage practices has not only dramatically reduced carbon export from the region, but the rebuilding of lost topsoil is undoubtedly improving agricultural production in the region as well.

Table 1. *Annual sediment and total carbon loads at the five catchment sites over time, percentage delivered as dissolved organic carbon, and equivalent CO_2 emissions.*

Site	Total agricultural area (hectare)	Time period	Sediment yield (tonne/year)	Total carbon yield (tonne/year)	Percentage delivered as dissolved organic carbon (%)	Equivalent CO_2 emissions by number of cars[1]
All years						
Paradise Creek (ID)	4,890 (3,032)	1979–1995	2,000	55	63	42
		2002–2011	700	48	85	37
Hooper, WA	647,497 (283,600)	1962–1971	2,000,000	25,000	12	19,097
		1992–2004	360,000	7,600	48	5,806
		2010–2012	70,000	4,400	83	3,361
2012 only						
Idaho CT outlet[2]	14	2012	79	0.8	2	0.6
Cook Farm (WA) NT[3]	11	2012	0.9	0.02	63	0.0
Paradise Creek at Darby Rd. (ID)	2,930	2012	1,600	57	84	43.8
Hooper, WA	647,497	2012	120,000	6,008	68	4,589

[1] Assumes 4.8 tonnes CO_2 emissions per vehicle per year
[2] CT = Conventionally tilled
[3] NT = No-till (direct-seed)

Nitrous oxide emissions protocols for the Pacific Northwest

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Nitrous oxide (N_2O) emissions from the use of nitrogen (N) fertilizers are a potent source of global greenhouse gas and also represent an economic loss to farmers. Reducing agricultural N_2O emissions improves environmental quality and potentially saves farmers money. Greenhouse gas emission reduction programs (e.g., Cap & Trade) establish the potential that voluntary farmer actions to reduce N_2O emissions may be eligible for incentive payments through carbon offsets. REACCH stakeholders have indicated significant interest in this strategy. Methodologies for quantifying emissions reductions have been developed for agricultural N_2O from N management, but available protocols have not been evaluated for the inland Pacific Northwest (PNW) (Table 1).

IMPACT

The financial incentive from carbon-offset credit alone is not likely to encourage any management changes. Stacking of offset credit revenue, along with other incentive-based approaches, is likely to be required in order to realize N_2O reductions in the region.

We reviewed five available N_2O reduction protocols and performed a road test to quantify N_2O emission offsets generated under PNW dryland wheat-based cropping systems. Our specific objectives were to: (1) use the protocol methodology to quantify emission reductions, (2) evaluate the relevance of the protocol methodology to PNW wheat-based cropping systems, and (3) consider the relative importance offsets may play in incentivizing future N_2O emission reduction strategies.

Using data and modeling assessments from the Washington State University Cook Agronomy Farm (CAF), three N_2O emission reduction scenarios were developed that could be feasible under PNW dryland wheat production: (1) switching from hard red to soft white winter wheat, (2) switching from hard red to soft white spring wheat, and (3) adoption of variable-rate N application in soft white winter wheat. Based on the CAF management records, estimated reductions as high as 75, 100, and 300 lb N/acre applied annually are possible for these three scenarios, respectively.

We evaluated the three scenarios under the two emissions protocols most likely to be eligible for PNW cropping systems—the Verified Carbon Standard and the American Carbon Registry. The first critical factor we encountered is the lack of a protocol-ready regional emissions factor (Tier 2) for the PNW. Without this factor, all protocols default to the Tier 1 emissions factor from the Intergovernmental Panel on Climate Change (IPCC) of 1% of applied N.

Using estimates from published experiments and modeling studies conducted in the region, we estimated an 0.2% emission factor as a potentially more realistic value for our region. For example, in our analysis of the CAF, shifting from hard red to soft white winter wheat resulted in a reduction of 20 tons of CO_2 equivalent for Tier 1, but only 8 tons of CO_2 equivalent for our estimated regional emission factor (Figure 1). Using the Tier 1 factor could significantly over-estimate both N2O emissions and potential N_2O reductions in our region. Therefore, an important

Table 1. *Protocol quantification methodologies reviewed and general eligibility requirements.*

Program	Protocol title	Eligible project locations	Eligible crops
Alberta Offset System	Quantification Protocol for Agricultural Nitrous Oxide Emissions Reductions	Canadian province of Alberta	Fertilized agricultural crops
American Carbon Registry	ACR1—The American Carbon Registry Methodology for N2O Emission Reductions through Changes in Fertilizer Management	Global	Fertilized agricultural crops
	ACR2—Methodology for Quantifying Nitrous Oxide (N2O) Emissions Reductions through Reduced Use of Nitrogen Fertilizer on Agricultural Crops	Global	Fertilized agricultural crops
Climate Action Reserve	Nitrogen Management Project Protocol	North-central region of U.S.	Corn
Verified Carbon Standard	Quantifying N2O Emissions Reductions in Agricultural Crops through Nitrogen Fertilizer Rate Reduction	U.S.	Fertilized agricultural crops

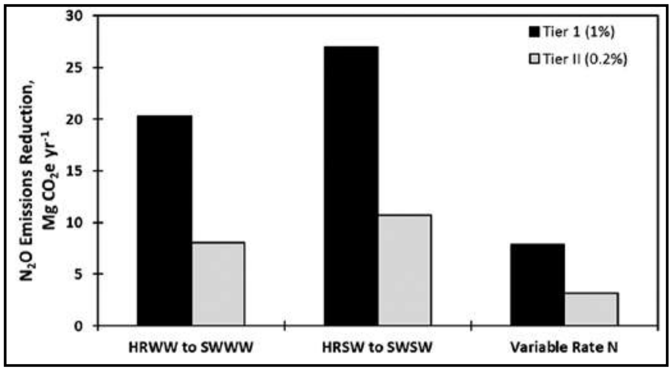

Figure 1. *Reductions in N_2O emissions for Tier 1 and Tier 2 emissions for three management scenarios.*

outcome of REACCH could be to develop protocol-ready emissions factor(s) for the region.

The second critical factor we encountered is that all of the existing N_2O reduction protocols utilize reductions in N application rate as a proxy for reductions in N_2O emissions. At least one prior study in the PNW indicates that the relationship between N application and N_2O emissions is not linear. Therefore, using N rate reductions and a constant emission factor to estimate N_2O reductions is not likely to be accurate. Realistically, using a model to estimate N_2O emissions reductions (IPCC Tier 3) would be the best strategy and is planned in the REACCH project.

The third critical factor we examined was the question of whether the value of a carbon offset credit for N_2O reductions would provide a sufficient incentive for farmers to implement any of the three scenarios we assessed. For carbon prices of $5 and $10 per ton CO_2 equivalent, the incentive ranges from $0.40 to $7.30/ha across the scenarios and Tiers. This incentive is not expected to be sufficient in itself to incentivize a management change. For carbon prices at $50 per ton CO_2 equivalent, the incentives range from $4.20 to $36.50/ha. However, when the value of expected cost savings on fertilizer application is included, the total monetary incentive ranges from $29 to $134/ha—an order of magnitude greater than the "carbon value," making the likelihood of implementation more realistic.

In order to support the participation of PNW farmers in offset credit markets for N_2O reductions, one or more of the existing protocols should be adapted for the region. At least a Tier 2 emissions factor will need to be determined or a model (Tier 3) will need to be utilized. However, the take-home message from this road-test assessment is that the financial incentive from the carbon offset credit alone is not likely to encourage any management changes. Therefore, stacking of offset credit revenue, along with other incentive-based approaches, is likely to be required in order to realize N_2O emissions reductions in the region.

Experiments using different N fertilizer rates help researchers and growers use N more efficiently. Photo by Slyvia Kantor.

Assessing crop performance with time-lapse photography

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In recent years, high-tech imaging devices involving satellites, drones, and even lasers have entered the discussion about how to develop improved, cost-effective decision support for precision agriculture. Our group (the Geospatial Laboratory for Environmental Dynamics at the University of Idaho) is working hard to improve the performance and usability of these high-tech tools in ecosystems ranging from the arctic tundra of northern Alaska, the tropical rainforest of Central America, and the rolling hills of the Palouse. There is enormous potential in these systems to help land managers and growers better understand the variability of crop performance, nutrient use, water availability, and weed and pest outbreaks across agroecosystems.

However, in a recent REACCH survey of 37 growers in the Pacific Northwest, 43% of respondents reported that they don't use available precision agriculture technologies because the equipment is too expensive. Furthermore, 30% said the software is too expensive or requires too much technical support or training, and 27% reported that it is too time consuming to learn.

IMPACT

Time-lapse photography has the potential to enhance crop performance and could be an effective precision agriculture management tool. High-tech tools may help us understand both natural and human-managed ecosystems better in the not-too-distant future.

Thus, we asked the following question: What about one of the most basic tools in our toolbox—a simple, color digital camera with the capability of taking time-lapse photos—all for the cost of about a tank of gas in your pickup? The objective of this report is to describe: (1) the ability of time-lapse imagery to estimate chlorophyll and nitrogen concentrations in spring wheat, and (2) the potential of this simple technology to aid as a decision support tool for precision agriculture.

During the 2012 and 2013 growing seasons, we mounted time-lapse cameras atop a 75-foot-tall tower at the Washington State University Cook Agronomy Farm (Figure 1), as well as on 5-foot-tall posts at four other farms at the top of small watersheds around the Palouse (Figure 2). Throughout the growing season, ground measurements of plant biomass, plant density, crop height, chlorophyll content, leaf nitrogen concentration, and soil moisture were collected at a total of 150 GPS points across all farms. Our main objective was to see how well simple vegetation indices (VIs) computed from the changes in colors captured by digital cameras might correlate to our ground measurements and add insight to improved crop management.

To quantify the amount of light energy that is reaching the camera for a given pixel in the image, we used a user-friendly software package called "ImageJ," which can be downloaded

Figure 1. *Troy Magney, raising the pneumatic pressure tower to 75 feet at the Washington State University Cook Agronomy Farm. The tower was gifted to the lab by NASA more than a decade ago. Photo by Lee Vierling.*

from the Internet at no charge. Each pixel on an image taken from any digital camera has digital numbers (DNs) between 0 and 255 associated with the brightness (the amount of light energy) being reflected in each band (red, green, and blue). Using the DN values for a specific pixel, we can calculate the relative percent brightness to account for daily changes in solar illumination (i.e., whether the image is darker or lighter at a different time of day).

For example, in Figure 3, we calculate the "greenness index" (GI) for each experimental plot. Plots received one of four different nitrogen application rates at planting (0, 40, 80, or 120 kg/ha). In the closest plot to the camera in Figure 3, the DN values for the red, green, and blue pixels were 75.5, 87.8, and 64.2, respectively—averaged over the entire plot area. To calculate the GI, then, the green band is divided by the sum of all bands (as a means to normalize the data): $G/(R+G+B)$, or $87/(75+87+64) = 0.386$.

This number is important because it provides a relative concentration of greenness (or chlorophyll); the lower the GI, the more chlorophyll, because more energy is being absorbed and used for photosynthesis. The result is likely to be higher biomass and, ultimately, higher yields. In Figure 3, the differences in chlorophyll content are indeed visible to the naked eye, but can now be quantified with the use of these tools.

For the particular plots shown in Figure 3, the GI was highly correlated to both relative chlorophyll concentration ($r^2 = 0.62$, $p < 0.01$) and total above-ground nitrogen ($r^2 = 0.73$, $p < 0.01$) during grain fill in spring wheat (July 26, 2013). These findings are consistent with previous studies using digital cameras to assess chlorophyll content. The utility of an entire growing season worth of daily imagery is likely to improve overall evaluations of crop performance, highlighting the high spatial variability inherent in most cropping systems. Additionally, our preliminary results from time-lapse imagery appear closely related to results from satellite imagery and in some cases outperform satellite imagery.

While the intent of this report was to focus on the ability of digital cameras to quantify the relative abundances of chlorophyll and above-ground nitrogen across the landscape, future work will seek to investigate the spatial dynamics of “wetting” and “drying” patterns on the field scale. This work could help to illuminate the spatial variability of water and nutrient availability across complex Palouse landscapes. Furthermore, it would provide high temporal resolution that might otherwise be missed by satellites that fly over only every 5 to 15 days.

Future work will use high-resolution digital camera data for evaluating soil water and nutrient availability as it relates to spatial crop dying dynamics, as well as toward predicted nitrogen use efficiency, yield, and protein concentration. Data available from time-lapse imagery is by no means an end-all decision support tool for assessing crop performance, but could continue to be a cost-effective, reliable, and user-friendly asset in the precision agriculture toolbox.

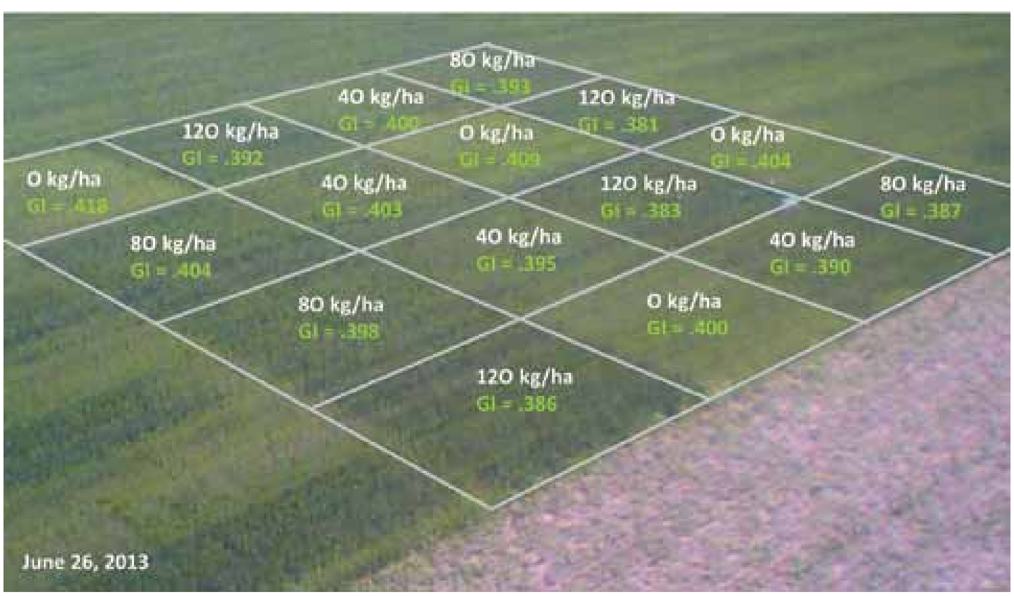

Figure 2 (above). *Selected time-lapse images from the 2013 growing season at a farm near Colfax, Washington.*

Figure 3 (left). *Experimental plots at the Washington State University Cook Agronomy farm. Each plot had a different nitrogen application rate at planting (shown in white). The associated greenness index (GI) value is shown in green. The GI is inversely proportional to the nitrogen application rate.*

Carbon credits from tilled and no-tilled winter wheat

Usama Zaher (zaheru@wsu.edu) WSU, Claudio Stockle WSU, and Kate Painter UI

Under the Pacific Northwest temperate climate and rainfall-limited dryland agriculture, a question of interest is the ability of wheat-based cropping systems to increase the storage of soil organic carbon (SOC) when conventional tillage (CT) practices are replaced by no-tillage (NT) or reduced tillage (RT).

As shown in Figure 1, NT management leaves residue biomass on the ground, while CT mostly incorporates these residues into the soil. Residue biomass is partially incorporated in RT, depending on tillage intensity. Thus, a key difference between CT and RT practices is that the former redistributes residues within the soil depth affected by tillage, while the latter concentrates residue accumulation on the topsoil. In addition, NT and RT reduce disturbance of the tilled soil layer, which reduces oxidation of SOC and carbon dioxide (CO_2) emissions.

To the extent that nitrous oxide (N_2O) emissions are significantly different between tillage management practices, the CO_2 equivalent of these emissions could affect the relative carbon footprints of the three tillage practices.

IMPACT

N_2O emissions constitute two-thirds of the winter wheat carbon footprint. No-till increases soil carbon sequestration in winter wheat drylands relative to conventional tillage, particularly on high rainfall areas. However, the dollar value of carbon credits resulting from reduced tillage is unlikely to be high enough to provide incentive for the adoption of reduced tillage practices. More efficient use of nitrogen fertilization can contribute to decreasing the carbon footprint independently of tillage management.

Differences in fuel consumption are also a factor when comparing management practices. Therefore, a life cycle assessment (LCA) approach considering several factors affecting the carbon footprint—not only SOC sequestration (storage)—is of interest when elucidating the potential for carbon credits derived from tillage reduction.

A crop simulation and LCA-based assessment of carbon credit potential in wheat systems in the Pacific Northwest was conducted. Table 1 summarizes the locations (representative of high, intermediate, and low rainfall zones) and crop rotations included in this study.

A cropping systems simulation model (CropSyst) was used for the assessment. The use of computer modeling ensures that the performance of the tillage practices is evaluated under the same set of environmental conditions. It also allows evaluation of changes during a long time span (in this case 30 years). It also accounts for progression toward a new equilibrium of SOC after the practices change. CropSyst is a comprehensive, process-oriented, multi-year, and multi-crop simulation model that can track daily crop growth and yield, as well as changes in soil water, soil nitrogen, SOC, and emissions of CO_2 and N_2O in response to climatic conditions and tillage intensity.

In addition to soil emissions, a standard LCA approach was used to estimate the emissions associated with agricultural inputs such as fuel, fertilizers, and pesticides. The carbon credit is evaluated as the reduction of carbon dioxide equivalent (CO_2e) emissions from all contributing sources. For example, N_2O is a

Figure 1. *Conventional tillage (left) increases soil disturbance and oxidation of soil organic carbon (SOC) compared to no-till management (right).*

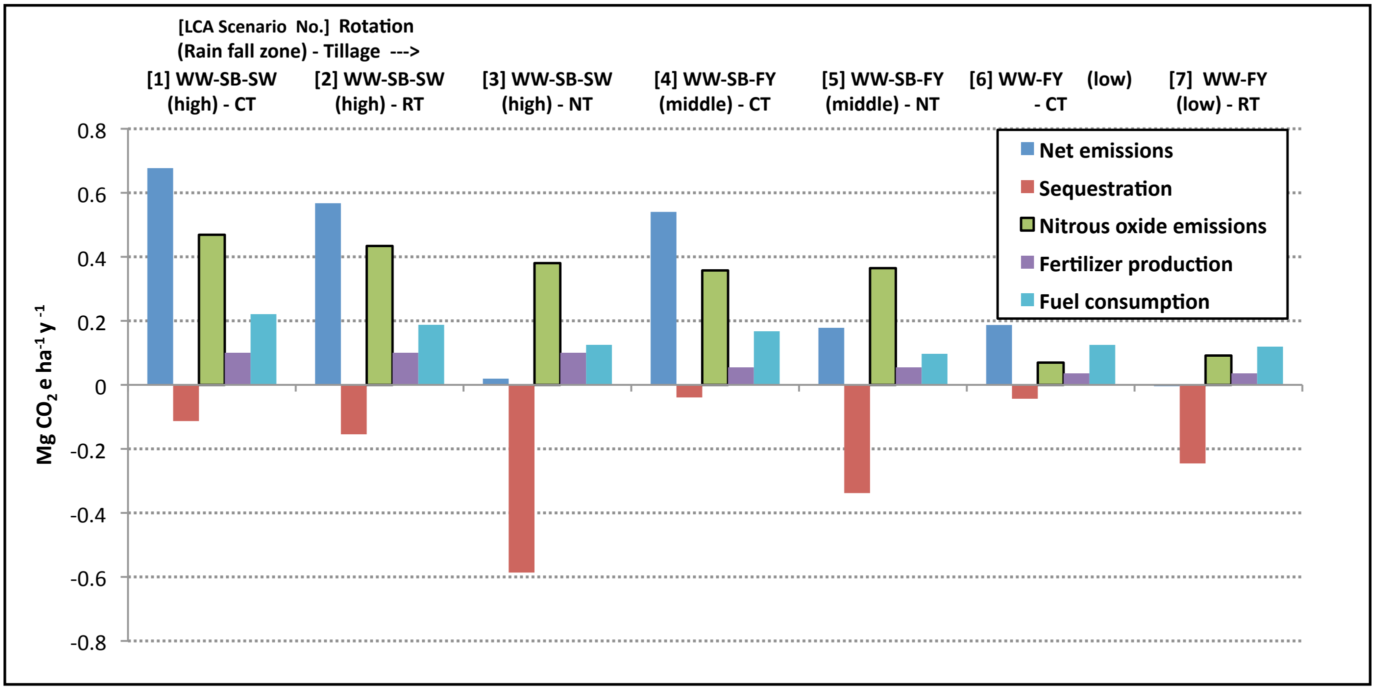

Figure 2. *Emission of equivalent carbon dioxide under different rainfall zones and tillage intensities for typical winter-wheat rotations in Washington.*

greenhouse gas that has 298 times the effect of CO_2 on potential global warming. Therefore, 1 gram of N_2O counts as 298 grams of CO_2 equivalent.

Figure 2 shows the CO_2 equivalent results for all locations, cropping systems, and tillage managements. Relative to conventional tillage, SOC storage increased with tillage reduction. SOC storage was higher in the high rainfall zone, and it decreased as lower rainfall limited residue production. The emission of N_2O was not significantly different in response to tillage.

The soil N_2O emissions and emission contribution from fertilizer production decreased in the lower rainfall areas as less N fertilization was used. Emissions associated with fuel consumption decreased with decreasing rainfall, biomass production, and tillage. In the low rainfall zone, there was little difference in fuel consumption between CT and RT, as mechanical weed control was replaced with chemical weed control. Emissions from other auxiliary processes such as equipment and pesticide production (not shown) were less than 2% of total emissions.

Assuming a carbon credit value of $2.50 per ton of CO_2 equivalent reduction (the historically low carbon credit in 2011), conversion from CT to NT in the high rainfall zone would generate $1.63 per hectare per year on average, while the medium and low rainfall zones would generate values of $0.90 and $0.45 per hectare, respectively. These figures are low. Even with a larger carbon credit value, they are unlikely to create additional incentives for tillage reduction. Improved management leading to reduced nitrogen fertilization could reduce N_2O emissions and the carbon footprint regardless of tillage management, particularly in the high rainfall zone.

Weather, climate, and agriculture

Von Walden (v.walden@wsu.edu) WSU

Given the central importance of climate and weather for REACCH, it is important to clearly define our terms. Both weather and climate concern varying conditions of the atmosphere, but they differ in temporal scale. Weather describes conditions of the atmosphere over a short period of time, and climate is how the atmosphere "behaves" over relatively long periods of time.

IMPACT

It is important to understand terminology in conversations between scientists and a lay audience. The effects of weather on agriculture are short term; the effects of climate change are long term and may require new adaptation and mitigation strategies.

Our best estimates are that future conditions in the inland Pacific Northwest will be warmer throughout the year, with larger temperature increases in summer. These changes are likely to increase the number of growing degree days and the length of the growing season. While models estimate an increase in annual precipitation, overall decreases in summer precipitation and increased evapotranspiration are likely to decrease water availability during the summer months.

Weather is important for agriculture, as it can be both beneficial and detrimental to crop production. On a year-to-year basis, weather influences the number of growing degree days, length of the growing season, and timing and amount of precipitation and evapotranspiration from crops. These factors can combine in advantageous ways for optimal growing conditions; however, a late spring freeze or lack of moisture during the growing season can severely limit yields and create a host of concerns for growers. Weather also determines the conditions under which pests appear in crops and how they might migrate. Over longer time periods, weather patterns shift, resulting in climate change or variability.

Our ability to forecast how weather changes day to day (weather), year to year, and decade to decade (climate) plays a vital role in keeping agricultural production flexible, adaptable, and cost effective. Research allows us to use models of the earth system to examine how weather variables may vary several decades into the future. Information from these models is "down-scaled" to fine spatial resolution that can then be used by agricultural researchers. Climate changes will differ among locations, just as weather does, so our down-scaling approach is similar to that used for shorter term weather forecasting. We can test these models by using them to project past climates and examine them for accuracy.

Our best estimate is for increases in temperature across the inland Pacific Northwest of about 3 to 4°F by the mid-21st century and between 4 to 6.5°F by the late 21st century, with a bit more warming during the summer months. Our best estimates suggest that annual precipitation will increase by about 5 to 15% by the middle and latter half of the 21st century. However, summertime precipitation is expected to decrease significantly. Along with warmer summer temperatures, the result will be a decrease in soil moisture during the late summer months.

Palouse wheat fields in Genesee, Idaho. Photo by Kathy Zenner.

In summary, our best estimates are that future conditions in the inland Pacific Northwest will be warmer throughout the year, with larger temperature increases in summer. These changes are likely to increase the number of growing degree days and the length of the growing season. While models estimate an increase in annual precipitation, overall decreases in summer precipitation and increased evapotranspiration are likely to decrease water availability during the summer months.

Photo by Brad Stokes.

Climate change and agriculture: Model projections

Liz Allen (lizb.allen@email.wsu.edu) WSU, Georgine Yorgey WSU, and Chad Kruger WSU

Farmers, industry representatives, and other citizens of the Pacific Northwest have pressing questions about agriculture and climate change. These questions include: How will climate change affect pest pressures and crop yields? How much carbon could soils in the region store? And, by how much is it possible to reduce nitrous oxide (N_2O)emissions? The only way to systemically address these and other pressing questions about future change is through a combination of experimental research and computer-based modeling. Applying information from models will require that stakeholders understand model assumptions and feel comfortable with interpreting the types of results that models provide.

The northeastern part of the REACCH Region in Eastern Washington. Photo by Roger Nelson.

IMPACT

Using and understanding appropriate models for your region and farming practices is critical in applying and making decisions for sustainable wheat production in the future under predicted climate change scenarios. REACCH is on the cutting edge of research by using coupled modeling frameworks to incorporate climate, cropping system, and economic models for a set of possible future scenarios to project agricultural productivity, potential types of agricultural practices, and profitability into the mid-21st century.

An oft-quoted maxim from scientist George Box says, “All models are wrong, but some are useful.” This is a way of saying that because models are simplifications they can never represent reality in all of its complexity. Yet, models can be useful because they allow exploration of how a system works and investigation of the relationships between various parts of the system. Models won’t ever give us the exact answer to the questions we ask, but they provide meaningful insight into likely outcomes. And, models can be valuable tools because they enable decision makers to evaluate how sensitive a system will be to a disturbance or change.

Experimental scientists and modellers from the U.S. Department of Agriculture-Agricultural Research Service, Oregon State University, University of Idaho, and Washington State University have been working closely together over the past decade to construct models of agricultural systems in our region. In these computer-based models, physical, biological, and, more recently, economic and social data are integrated, based on the best available scientific literature. Throughout the process, experimental scientists work with modellers to test and evaluate model results against empirical data from our region. Multiple models are being developed and tested in our region, and as different models begin to suggest similar future conditions, researchers feel increasingly confident in the reliability of model results.

Stakeholders are generally experienced at understanding the context in which a certain set of experimental results was obtained. For example, they know that having information about the soils, rainfall, and crop rotation in which results were measured can help them evaluate whether similar results might occur on their farm. Similarly, for modeling results, it is critical to understand the model’s built-in assumptions in order to assess the

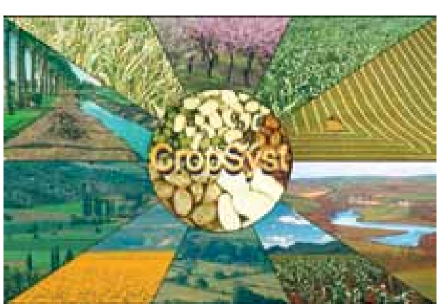

Figure 1. *CropSyst is a user-friendly, conceptually simple, but sound multi-year, multi-crop daily time step simulation model. The model has been developed to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion.*

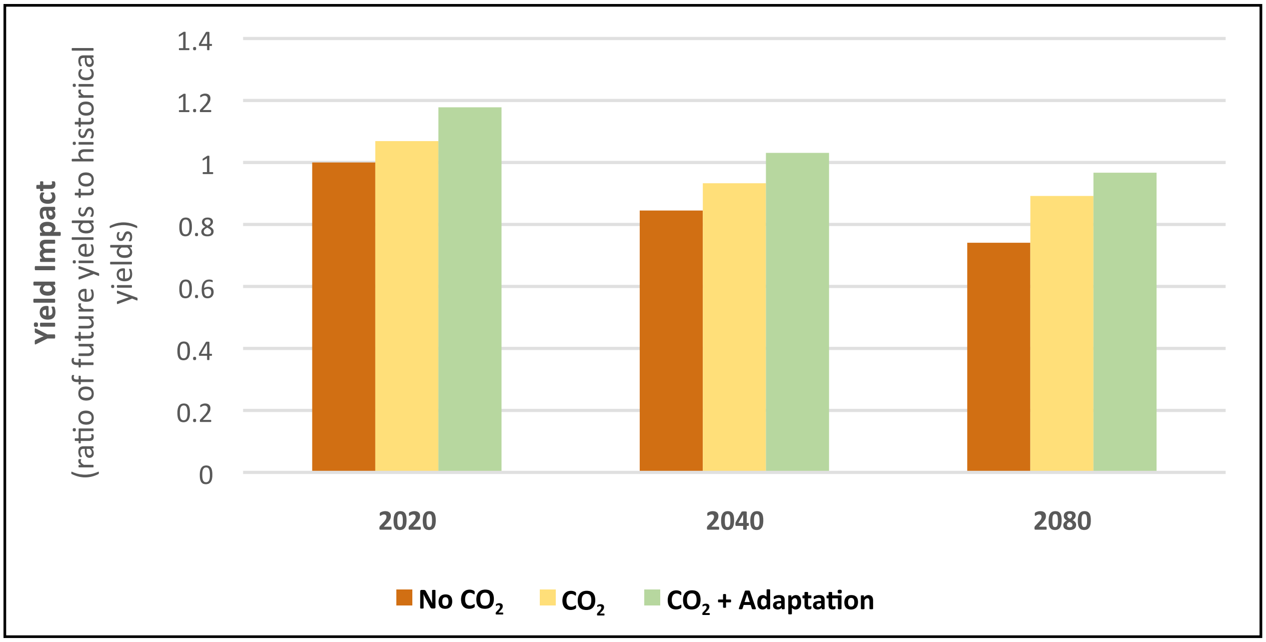

Figure 2. *Modeled impact of climate change on yields of spring wheat in St. John, Washington (2020, 2040, and 2080). A value of "1" on the graph indicates no change from the baseline historical yield. The scenario "no CO_2" includes the impacts of changes in precipitation and temperature, while "CO_2" also includes the impact of increased CO_2 concentration on plant growth, and "CO_2 + adaptation" also includes the impact of planting 2 weeks earlier.*

relevance of model-generated results. Looking at one example of previous modeling work in our region can illustrate how this is helpful.

CropSyst (Figure 1), a cropping systems simulation model, has been used frequently in the Pacific Northwest to address questions about the impacts of climate change on agriculture. In 2010, as part of the Washington Climate Change Impact Assessment Project, CropSyst was used to study potential climate change impacts on yields of three economically important Pacific Northwest crops at specific representative locations. Crops and locations were as follows: winter wheat (modeled at Pullman, Saint John, Lind, and Odessa, Washington), spring wheat (Pullman, Saint John), potatoes (Othello, Washington), and apples (Sunnyside, Washington). Overall, model projections suggested that climate change impacts on these crops would be mild over the next 2 decades, but more risky by the end of the century.

However, understanding the specific assumptions underlying the model scenarios generates additional insight into this general conclusion. Figure 2 shows the changes projected for spring wheat in St. John, Washington, under three different sets of assumptions in the CropSyst model. In general, by 2040, climate changes are projected to have a negative impact on spring wheat yields, if only changes in temperature and precipitation are considered (orange bar). However, these potential negative impacts are counter-balanced by benefits from increased carbon dioxide levels on plant growth (called the "CO_2 fertilization effect") (yellow bar) and by the fact that growers may be able to plant earlier (green bar).

It is also important to understand that while the study considered changes in climate, the impacts of increased CO_2 on plant growth, and a few possible adaptations by farmers, there are numerous other expectations built into the model. These include assumptions that crops would receive adequate nutrients; that weeds, pests, and diseases would be controlled; and that irrigated crops would receive adequate water. Each of these assumptions merits further scientific evaluation and, in some cases, new scientific investigation. For instance, a key effort of REACCH scientists is to incorporate potential climate change impacts on weed, pest, and disease pressures into modeling efforts.

In an effort to further facilitate the understanding of REACCH modeling results, we are developing a more comprehensive fact sheet introducing stakeholders to some of the fundamental considerations of interpreting environmental modeling results. We anticipate that this fact sheet will be available in spring of 2014 and will be available on the REACCH website.

Ripe wheat ready for harvest. Photo courtesy Stone-Buhr Flour Company.

End-of-the-century climate and Pacific Northwest wheat production

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In order to sustain long-term profitable wheat production in the Pacific Northwest, scientists, agribusiness, and producers need to understand climate change trends into the future. Integrated climate and cropping system models enable us to predict regional precipitation and temperature to the end of the century. What we know about the potential impact of climate change on Pacific Northwest wheat production points toward a future that, assuming appropriate management and adaptation, might bring an increase in productivity for the region, along with somewhat limited concern for dramatic adverse effects.

IMPACT

Toward the end of the century, predicted hydrological cycle changes are unlikely to have a significant impact for dryland wheat production. What we don't know with certainty is the rate and magnitude of future climate change as influenced by societal decisions and technological innovation. The effects of future warming trends can be mitigated with informed cultivar selection and management. Increases in CO_2 concentration may increase biomass produced per unit of water use, benefiting Pacific Northwest farmers. In the near future, REACCH will study the little-understood impact of climate change on pests, diseases, and weeds that could increasingly affect wheat production and cost.

By the end of the century, precipitation in the Pacific Northwest is projected to change by -1.8 to 12.5%, with a higher winter concentration and a trend to some decrease in the summer, compared to today's precipitation patterns. In terms of temperature, there is a clear trend toward warming, with mean annual temperatures in the region increasing 3.1 to 11.7°F. Concurrently, atmospheric carbon dioxide (CO_2) concentration will increase from today's average of about 400 ppm to somewhere between 538 and 936 ppm, depending on future emissions of greenhouse gases.

The productivity of the region's wheat-based dryland agriculture depends directly on the amount and distribution of precipitation. Annual precipitation ranges widely across the region, from about 7 to 24 inches, thus influencing cropping intensity and use of fallow years. Although concurrent warming will produce alterations to the hydrological cycle (for example, less snow accumulation), these changes are unlikely to have a significant impact for dryland wheat production, with crops continuing to utilize all soil-available water for growth and yield.

The impact of warming could be of more consequence. Assuming that vernalization and day length requirements of cultivars are well adapted to environmental conditions, the progression of wheat development is directly dependent on the accumulation of degree days (the sum of daily mean temperature above a base temperature). Thus, warming will tend to shorten the number of days between emergence and maturity. A shorter growing season

Photo by Brad Stokes.

implies that the amount of solar radiation capture will be reduced, thus reducing the accumulation of biomass and grain yield.

Fortunately, adaptation to this condition is possible by selecting winter wheat cultivars with a slower rate of development that can better utilize the longer available growing season resulting from warming. In the case of spring wheat, earlier planting is a way to adapt to an accelerated growing season. Another impact of warming, which can be extremely damaging, is excess heat during pre-flowering and flowering. Grain numbers can be substantially reduced by a few days of early daylight hours with temperatures above 88°F during this sensitive period. This is an impact of great concern in southern latitudes of wheat production in the United States, but it is unlikely to be a significant factor in the Pacific Northwest unless the most extreme warming projections become reality. In the end, with informed cultivar selection and management, wheat production in the region likely will continue to be more affected by water limitation than by other factors.

What about the increase of atmospheric CO_2 concentration? This greenhouse gas is the most important contributor to climate change. Nonetheless, many crops, especially those with the so-called C_3 biochemical photosynthetic pathway, will benefit from increased atmospheric CO_2 concentration. The majority of crops, including wheat, fall into this group.

Photosynthetic rate depends on CO_2 concentration within the leaves, with the rate increasing linearly at first, and then non-linearly (at decreasing rates) in response to increasing internal CO_2 concentration. Eventually, the internal CO_2 concentration reaches a maximum saturation value at which no further photosynthetic rate increase occurs. At current atmospheric CO_2 concentration, wheat photosynthesis operates at an internal CO_2 concentration of about 280 ppm, while saturation is reached at about 580 ppm. Another beneficial effect of increasing CO_2 concentration is that stomata reduce their aperture, which results in less water loss (partially counteracted by slightly larger crop canopies). The combination of these effects increases the units of biomass produced per unit of water use, a fact that can be beneficial for Pacific Northwest dryland wheat production. These types of responses have been well documented in the scientific literature.

Altogether, what we know about the potential impact of climate change on Pacific Northwest wheat production seems to point toward a future that, assuming appropriate management and adaptation, might bring an increase in productivity for the region and somewhat limited concern for dramatic adverse effects. Now, what about what we do not know?

There is a large degree of uncertainty in the projection of future climate, particularly regarding rate and magnitude of future climate change. Although the long-term warming trend is a point of agreement among more than 20 climate models, there are large discrepancies among them regarding the rate of increase. This variation is compounded by different possible future CO_2 emission scenarios and pathways for atmospheric CO_2 concentration increase as conditioned by societal decisions. We do not know which of these projections will materialize, and thus we cannot be certain about the extent of negative or positive impacts on wheat production.

More troubling is the lack of clarity about the extent to which climate change will lead to more extreme events, with these extremes damaging crop canopies due to cold weather or reducing grain set due to extreme heat events. Also, there is little understanding of the impact of climate change on pests, diseases, and weeds that could increasingly affect wheat yield and production cost.

Photo by Brad Stokes.

Regarding the beneficial impact on biomass production of increasing atmospheric CO_2 concentration, the rate of gain eventually decreases, becoming flat at about 880 ppm, a concentration that could be reached by the end of the century. Finally, there is also uncertainty about the speed of technological innovation and adoption that would allow Pacific Northwest wheat producers to adapt to changing conditions and perhaps reap the benefits of farming in a potentially less affected region compared to others in the United States.

Why hasn't spring warmed?

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

Agriculture is a seasonal endeavor. Weather accrued during each season can profoundly impact farmers and the crops they produce. Variations in weather patterns and seasonal temperatures can affect cropping decisions, timing of field operations (e.g., planting or spraying), and pest cycles. As a result, weather is a daily conversation topic for farmers, who are constantly trying to guess what it's going to do so they know what they should do next.

IMPACT

Seasonal climatic cycles can greatly impact the management decisions that farmers have to make. Better understanding of current weather patterns and seasonal variability could help prepare farmers to adapt to climate changes in the region.

Weather is expected to become even more unpredictable as the global climate changes, and some understanding of current weather patterns and seasonal variability could help prepare farmers to adapt to changes in the region. REACCH scientists at the University of Idaho and Oregon State University are providing some new insights on how and why seasonal climate has changed over the past century in the Pacific Northwest. Examining regional temperature changes based on seasons, instead of just annual changes, makes for a complex, but interesting, story.

The regional annual average temperature has increased by nearly 1.3°F over the past century. This overall warming trend has been apparent in all seasons over the past century, with the general rate of warming increasing more in recent decades (Figure 1). Although it contains substantially more year-to-year variability, the upward trajectory of temperature change for the Pacific Northwest mirrors that of the global mean temperature. However, spring temperatures have cooled slightly over the past 3 decades, most notably since the early 1990s. Why is this?

Many factors influence the global climate, including volcanic eruptions, solar output (the total radiation coming from the sun), natural climate variability (such as El Niño and the lesser known Pacific North American pattern), and human-caused change (the factor most prominently associated with global climate change). Analyzing these factors suggests that the observed spring cooling is largely the result of natural climate cycles that temper the pace of regional anthropogenic warming.

The influence of natural climate variability is most pronounced during the winter and spring in the Pacific Northwest. Temperature trends during these seasons over the past several decades were strongly influenced by these factors. For example, approximately 40% of winter warming since 1950 seems to be linked to atmospheric circulation that favored the movement of warmer air masses into the region. Conversely, circulation patterns have contributed to a significant cooling of spring temperatures since 1980, thereby masking warming contributed by anthropogenic factors. In the absence of these cycles, spring warming of approximately 0.8°F over a 30-year span likely would have occurred.

Despite the recent cooling observed in spring temperatures, longer term trends show that spring temperatures have increased, with the decades of the 1980s, 1990s, and 2000s being the second, first, and fourth warmest decades since 1900 across the region. Prior to the 1980s, the 1930s was the warmest decade on record.

Spring temperature cycles are clearly observable in Figure 2, showing mean spring temperatures in Pomeroy, Washington. The mean springtime temperature for the entire time period (1930–2013) was 46.5°F, and departures from that mean can be observed for each year (red bars when mean temperature exceeded 46.5°F, blue bars when mean temperature was below 46.5°F). The black line shows the 11-year running mean and makes the cycles evident by illustrating that periods with cooler-than-average spring temperatures are followed by periods with warmer-than-average temperatures.

Research also documented the lengthening of the freeze-free season across the Pacific Northwest by nearly 2 weeks. Also, the coldest night of the year has warmed by an average of 5°F since the mid 20th century. Although the last spring freeze has not shown any change over the past 3 decades, coincident with the

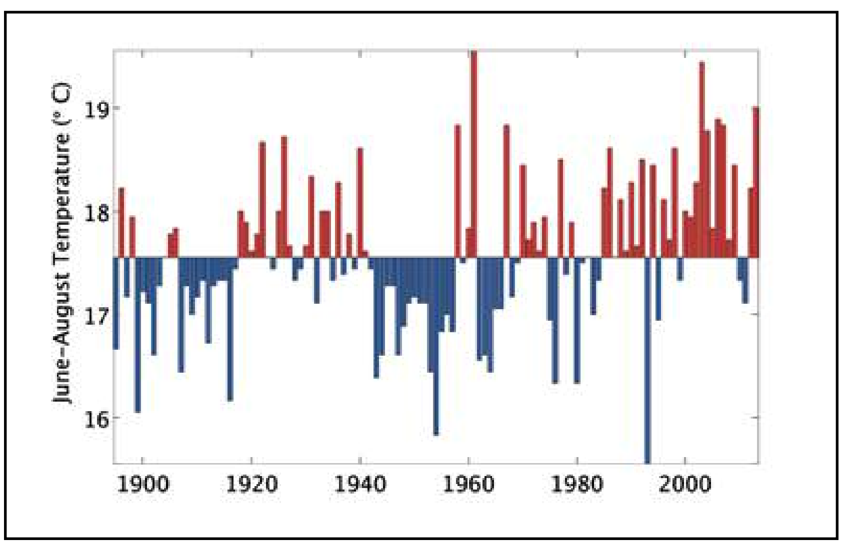

Figure 2. *Spring (March–May) mean temperature (1930–2013) for the Pomeroy, Washington United States Historical Climate Network station acquired using the WestWide Drought Tracker. Red and blue bars show anomalies from the 1981–2010 base period, and the black line shows the 11-year moving average.*

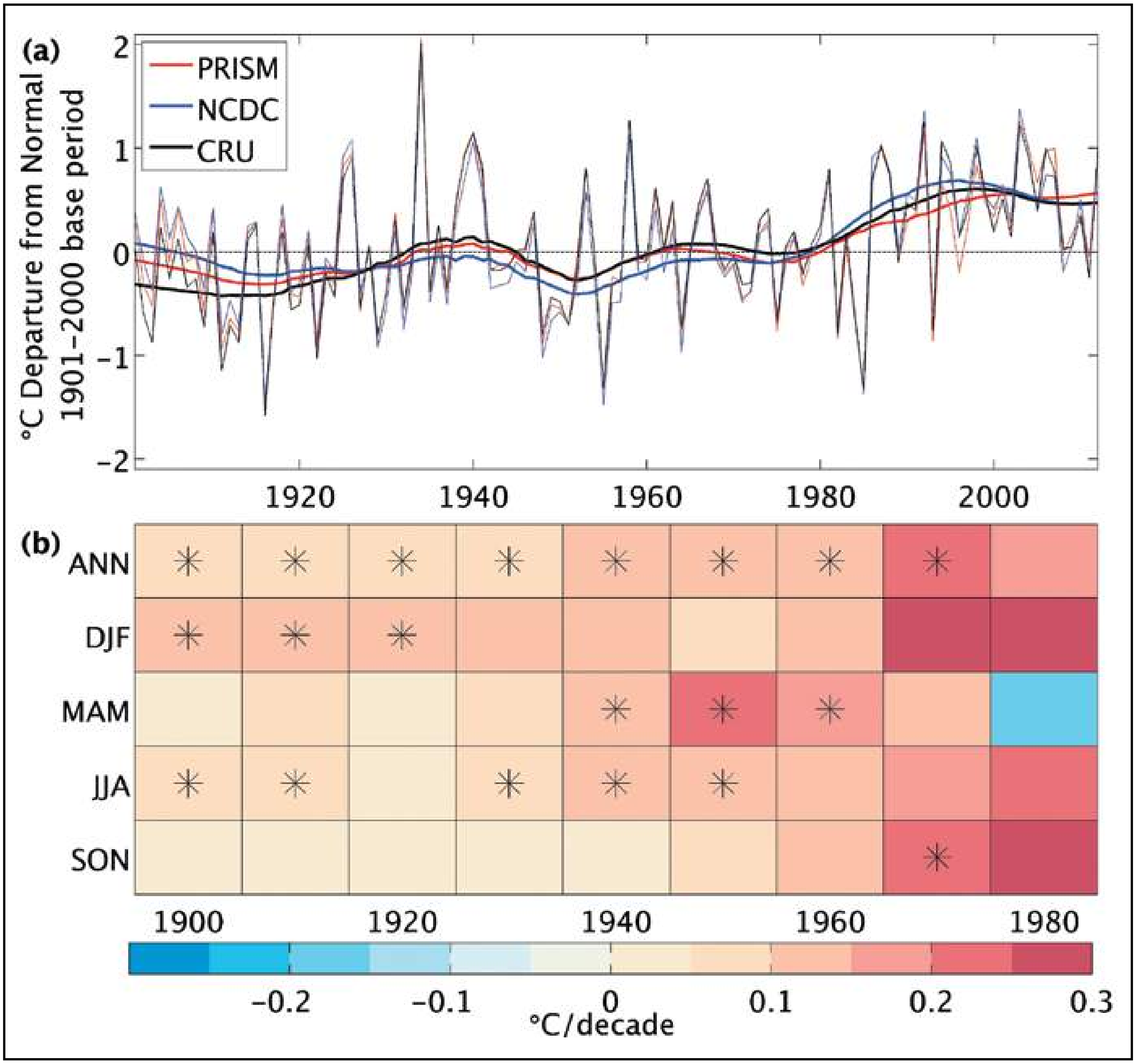

Figure 1. *(a) Annual regional mean temperature anomaly derived from three different data sources: PRISM (red), NCDC divisional data (blue), and CRU (black), 1901–2012. Anomalies are taken with respect to the 1901–2000 period. Thin lines show annual data, and bold lines show a local weighted regression. (b) Linear least squares trend in regional mean temperature (°C) per decade. Mean temperature is averaged over the calendar year and for each season for the time interval beginning with the year on the bottom axis through 2012. An average of the anomalies computed for the three different data sets is used in (a). Statistically significant ($p < 0.05$) trends are denoted by *.*

lack of springtime warming, the first autumn freeze has been delayed by around 1 week across the Pacific Northwest since 1980.

Longer freeze-free seasons and a lack of extremely cold winter temperatures may be advantageous to agricultural productivity and pests alike. Decreased winter mortality rates with warmer winter temperatures may increase insect populations. Likewise, a longer freeze-free season may allow for additional generations, which might require additional control measures to capitalize on any potential agricultural benefits of warming.

Better understanding of these climate cycles, and the combined impact of multiple drivers on seasonal climate, is of critical importance to agricultural producers, particularly in light of a changing climate. The natural factors that have resulted in cooler springs are not likely to continue indefinitely. Instead, it is likely that when these processes reverse, and large-scale natural factors and human-caused greenhouse forcing are acting in the same direction, we will see significant seasonal warming.

Climate change loads the dice for hot summers

John Abatzoglou (jabatzoglou@uidaho.edu) UI, Katherine Hegewisch UI, and Lauren Parker UI

With long days, comfortable temperatures, little rain, and ample sunshine, the Pacific Northwest is one of the nicest places to be during the heart of summer. Summer temperatures are also ideal for the region's agriculture. Although the region has historically experienced occasional "hot" summers, they are likely to become the new norm in the 21st century under climate change.

While a hot summer may be a boon for the air conditioning salesman, increasing summer temperatures may prove a challenge for farmers making cropping decisions, and they can be detrimental to wheat production if temperatures rise too high during critical growth stages. In order to better understand the implications of climate change on future summer temperatures, REACCH scientists at the University of Idaho are looking at models of possible futures and comparing them to historical observations in order to understand how seasonal temperature trends are projected to change.

IMPACT

Pacific Northwest summer temperatures are projected to increase over the 21st century, and temperatures that were considered heat extremes in the 20th century likely will become increasingly widespread and the new normal. By understanding these observed trends and projected regional climate in the summer months, we can help agricultural producers develop climate-appropriate agricultural plans to maximize their production over the long term.

Observed trends in mean annual temperature in the Pacific Northwest show a long-term warming trend. Increases in temperature have not been monotonic, but rather follow an irregular incline, with warming rates waxing and waning under the influence of natural climate variability. However, the year-to-year variability in summer temperatures throughout the Pacific Northwest is only approximately half as great as that seen in winter temperatures.

One explanation for this is that the year-to-year variability in summer temperatures is reduced due to the limited influence of large-scale climate cycles, such as El Niño, since the jet stream is displaced well to the north during this season. The overall result is that the reduced variability in summer temperatures makes the influence of anthropogenic warming more apparent in the summer than in other seasons. Figure 1 shows long-term observations of summer temperatures for the Pacific Northwest, where a warming trend is particularly notable since 1970. Summer temperatures (June through August) have increased by nearly 1°C.

Small year-to-year variability in summer temperatures means that a "hot" summer, one that might be expected only once ever 20 years (or has a 5% chance of occurring in any given summer), may actually be only a couple degrees (e.g., 2°C) above the long-term normal. For instance, if the baseline summer temperatures across the region increase by 1°C, instead of needing exceptional conditions to achieve a "hot" summer, a modestly warm summer (e.g., 1°C above the new baseline) would qualify as a "hot" summer with respect to the longer term perspective.

Some of the warmest summers in the Pacific Northwest have occurred over the past 10 years. The gray bars in Figure 2 show the percentage of landmass in the Pacific Northwest experiencing a 1-in-20 warmest summer, as defined over the historic period. More than 90% of the region was "hot" in the summer of 1961. While parts of the Pacific Northwest may experience hot temperatures in any given summer, widespread hot temperatures across the region (those affecting at least 25% of the area) were observed in 1958, 1961, 1967, 2003, 2006, 2007, 2012, and 2013. Overall, the number of years with widespread summer heat has increased significantly. Thus, the increase in baseline summer temperatures has acted to "load the dice" on hot summers by increasing the odds of experiencing a hot summer from 1 in every 20 years on average to 1 in every 5 years on average.

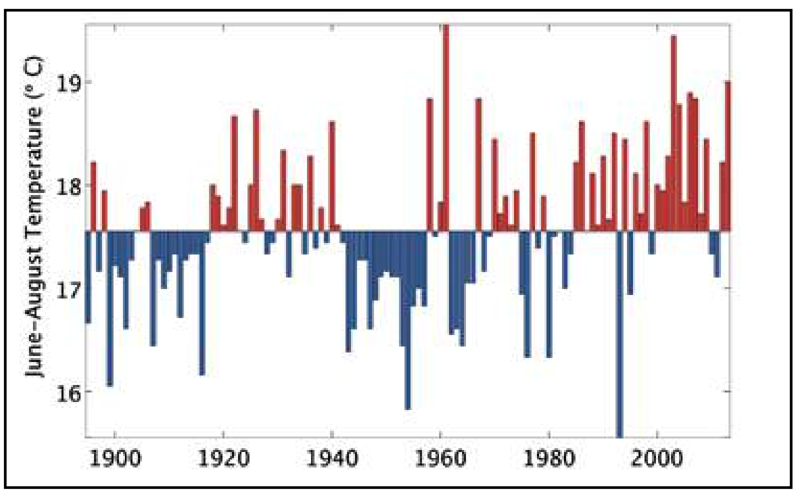

Figure 1. *Average summer (June, July, August) temperatures for the Pacific Northwest (Washington, Oregon, Idaho) from 1900 to 2013 are shown as anomalies from the average over the entire period (about 63°F). Blue bars indicate colder than average, and red bars indicate warmer than average summer temperatures. A significant increase in summer temperatures is seen for the past 60 years, with summer temperatures over the past decade being the highest in the observational record (1895–2013).*

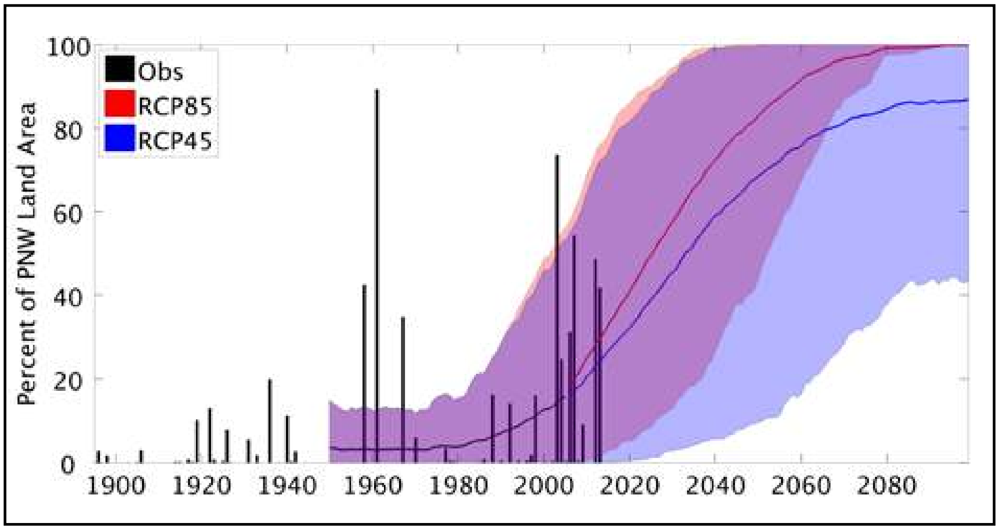

Figure 2. *Percentage of Pacific Northwest landmass experiencing summer (June, July, August) temperatures greater or equal to the warmest 5% of summer temperatures in the historical record (or approximately 1-in-20-year temperatures). Observed ("Obs") percentages are the grey bars. They consider the observational record from 1895 through 2013. The projected percentages under the RCP85/RCP45 future scenarios of CMIP5 are shown smoothed by a 21-year moving window, with red and blue lines representing the multi-model mean. Pink and blue shading represent the range of model projections. Model projections over the historical period (1950–2005) were run using historical forcing.*

How will climate change further alter the odds of a "hot" summer for the Pacific Northwest? To address this question we used output from a suite of global climate models from phase 5 of the Coupled Model Intercomparison Project (CMIP5) down-scaled to the spatial scales needed to understand local climate impacts. We considered two possible "futures," called Representative Concentration Pathways (RCPs), which account for the additional energy trapped in the earth's atmosphere due to increased greenhouse gas concentrations and land use changes. The two scenarios we used included the "business as usual" RCP85 and the "curtailed emissions" RCP45 pathways. A historical scenario that considered observed changes in natural and human-induced climate influences was also considered from 1950 through 2005. Down-scaled data from 14 different climate models under the 2 future scenarios were used to examine how future human-made changes in climate may impact the frequency of hot summers in the Pacific Northwest.

Climate projections for the Pacific Northwest generally suggest that the highest rates of warming will occur during the summer months. Figure 3 shows the projected changes in temperature over the Pacific Northwest for the 14-model average under RCP85. These projections place the most acute warming over the interior Pacific Northwest, with reduced warming for areas with significant maritime influence. Although projected warming varies from model to model, by the 2030s and 2040s, all models show warming exceeding 1°C, and some models show warming exceeding 4.5°C above the historical baseline. This warming is anticipated to continue through the 21st century and is particularly acute for pathway RCP85. By century's end, summer temperatures are projected to increase between 2 and 8.5°C above historical baseline temperatures.

Under the RCP85 future pathway, the currently rare 1-in-20-year "hot" summer becomes increasingly common, and by the 2030s–2040s occurs 3 out of every 4 years on average (Figure 2). By the 2060s–2070s, it becomes exceedingly rare to not experience a summer that we currently consider "hot." The alternative pathway, RCP45, shows a more modest increase in the number of "hot" summers among models with the lowest warming rates. However, the observed increase in the extent of such hot summers in recent decades is consistent with model projections and anthropogenic forcing, suggesting that these changes are already underway.

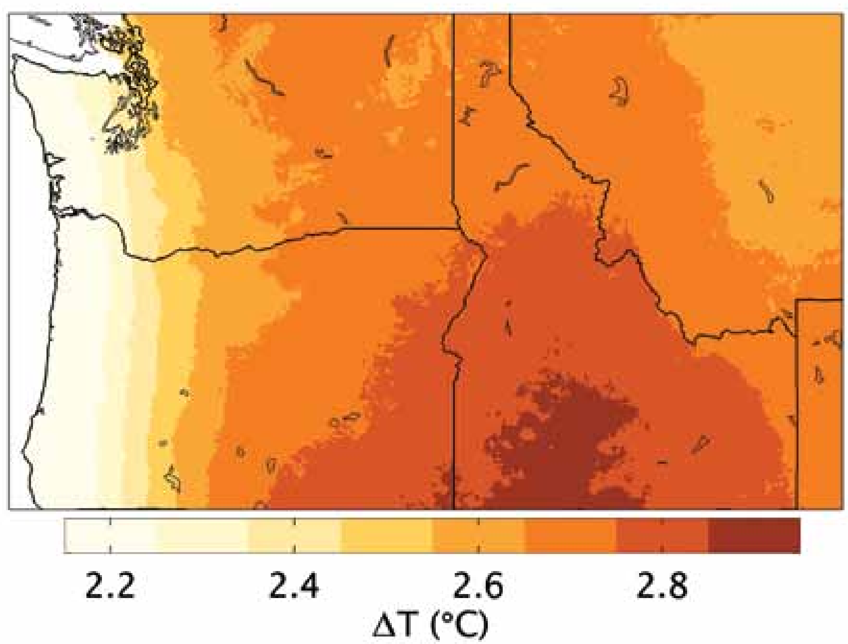

Figure 3. *Projected changes in average summer (June, July, August) temperatures for 2031–2050, as compared to averages from 1950–1999, are shown for the 14-model average under the RCP85 future scenario. Greater warming (up to nearly 3°C) is anticipated for the inland Pacific Northwest, with less warming (nearly 2°C) expected in coastal regions.*

Mountain snow and inland Pacific Northwest agriculture

Philip Mote (pmote@coas.oregonstate.edu) OSU, David Rupp OSU, and John Abatzoglou UI

Much of the irrigation water that feeds Pacific Northwest agriculture originates as snowmelt. While human-made reservoirs provide some storage of spring snowmelt that can be released during the summer for consumptive use, reservoir storage is only a small fraction of the storage that snow provides in most basins. Consequently, anything that affects snow storage could have a profound effect on summer water supply and thus agricultural production.

Research has shown that year-to-year variations in many hydrologic variables are strongly influenced not just by total precipitation but also by seasonal temperatures. Statistical analysis establishes strong relationships between springtime temperature and: (1) timing of snowmelt, (2) amount of snow on the ground on a given date in spring, and (3) summer flow in unregulated (undammed) rivers. For example, in March 2004, the western United States experienced extremely warm conditions and record high rates of snowmelt.

IMPACT

Mountain snowpack is vital for irrigated crops in the inland Pacific Northwest. Predicted long-term warming trends may impact the timing of snowpack melt and consequently affect water storage, irrigation systems, and production costs in the region.

In addition, long-term trends of these variables also reflect long-term warming trends. For example, Figure 1 shows that most stream gauges with long enough records (since 1948) have seen a long-term reduction in the 25th percentile of lowest annual flows; the dry years are getting drier. Figure 2 compares April snowpack from high-resolution regional climate modeling for 1960 through 2009 (supported in part by REACCH) with observed trends for 1960 through 2002. (More recent data have not been analyzed.) Mountain areas generally see declines in spring snowpack except at higher elevations, which see the effects of warming later in the year.

Our data show springtime temperatures in the Pacific Northwest rose for awhile and then cooled again. The warming that produced the changes shown in Figures 1 and 2 was followed by cooler than average spring seasons in the past 5 years, which have also seen generally healthy snowpack (except 2013, a drought year).

Long term, scientists expect warming to resume and, with it, the reductions in spring snowpack and summer streamflow that were observed over the past 50 to 60 years.

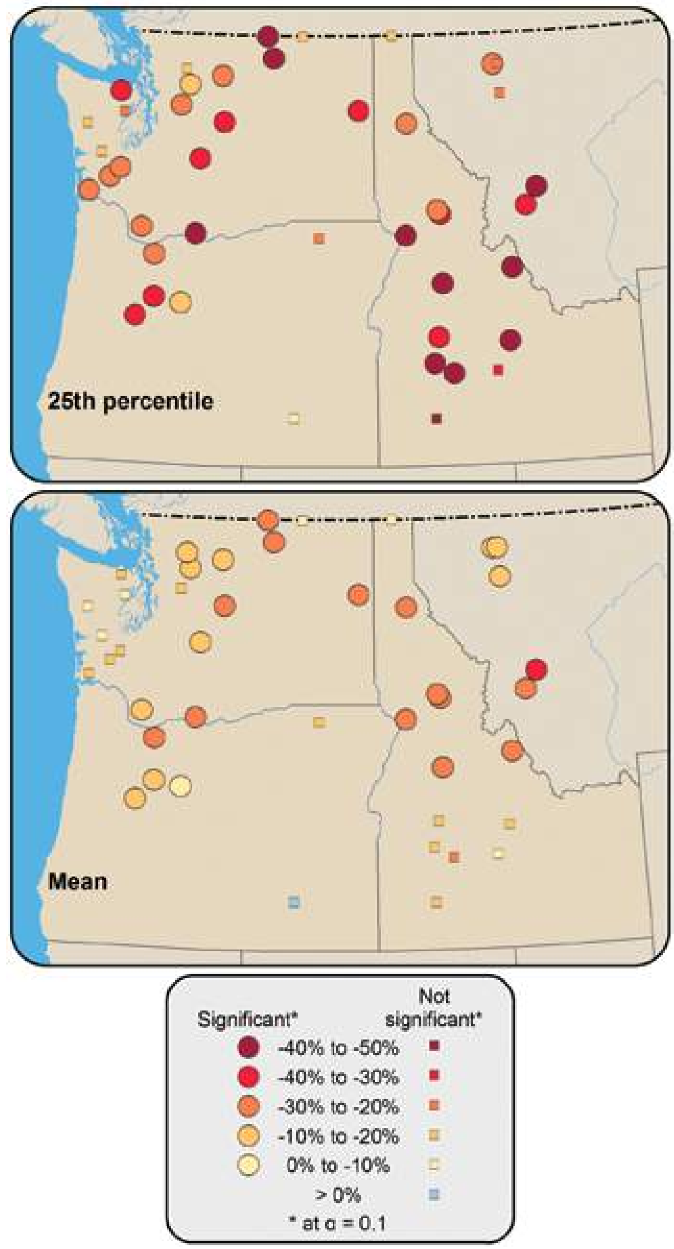

Figure 1. *These maps depict the changes in 25th percentile annual flow (top) and mean annual flow (bottom) at streamflow gauges across the Northwest for 1948–2006. Circles represent statistically significant trends (at α = 0.1), whereas squares represent locations where the trend was not statistically significant.*

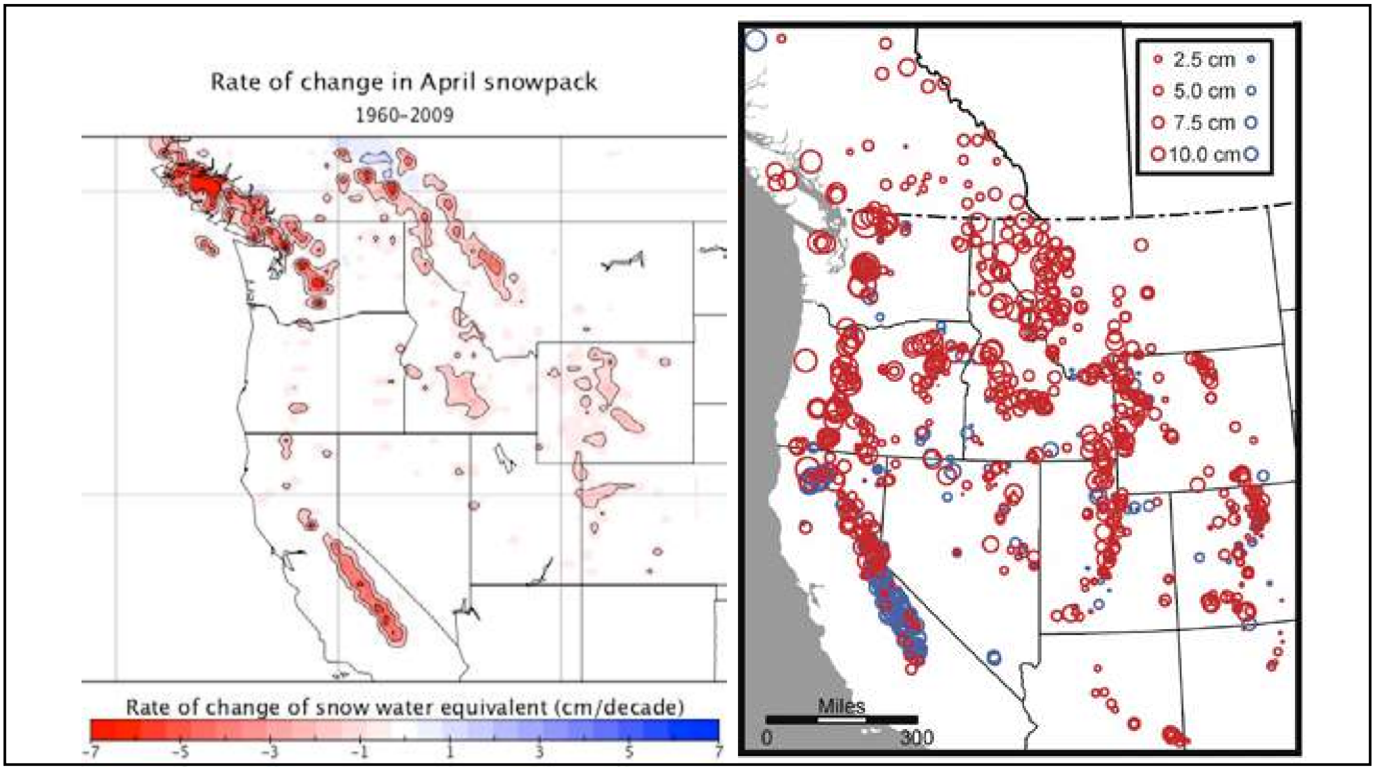

Figure 2. *Linear trends in snow water equivalent from: (1) the weatherathome simulations (1960–2009), averaged for the month of April, and (2) observations (1960–2002) for April 1. Red indicates declines and blue increases. Approximately 75% of the observations experienced declines, and most of the increases are in the southern Sierra Nevada mountains, where precipitation increased over the period shown here.*

Center pivot irrigation system. Photo by Sylvia Kantor.

Training graduate students to work across disciplines

Jodi Johnson-Maynard (jmaynard@uidaho.edu) UI, Sanford Eigenbrode UI, and Kristy Borrelli UI

Preparing scientists and educators to create and promote practical science-based agricultural approaches to climate change adaptation and mitigation is a main focus of REACCH. Social, political, and environmental complexities and interactions require that future scientists work across disciplines rather than having isolated knowledge of one specific subject area. Additionally, it is important for graduate students earning M.S. or Ph.D. degrees in agriculture and climate sciences to be able to communicate scientific findings effectively to non-scientific audiences.

IMPACT

Social, political, and environmental complexities and interactions require that future scientists work across disciplines rather than having isolated knowledge of one specific subject area. Tomorrow's scientists will be well trained to address difficult and intricate agricultural and climatic issues.

Unfortunately, university graduate curricula rarely adequately prepare students with these important skills. REACCH recognizes the need for graduate students to have thorough exposure to other disciplines and to be able to communicate information for outreach and education purposes. These priorities have been incorporated into graduate training within the REACCH project. The interdisciplinary nature of the project and its sophisticated digital infrastructure provide graduate students multiple opportunities to gain these experiences.

Currently, REACCH has 24 graduate students (15 Ph.D. and 9 M.S.) and 6 post-doctoral researchers participating in the project. Students have diverse interests in approximately 20 disciplines, and their research foci include: agronomy, carbon and nitrogen cycling, crop residue and carbon analyses, soil quality management, no-till and precision agriculture, hydrologic and greenhouse gas fluctuations, pest and beneficial organism dynamics, economics, communication, surveys and public participation modeling, modeling biogeochemical processes, remote sensing, science education and ethnography, and climate change. This diversity of disciplines reflects the breadth of the REACCH project. The REACCH infrastructure allows students to interact through distance collaboration tools, at in-person annual meetings and retreats, and, in some cases, shared research sites and data sets.

Creating a sense of community is challenging because REACCH graduate students and post-doctoral scientists are working at three academic institutions across a large geographical region. To address this, REACCH hosts annual graduate student retreats. The meetings are typically 2 to 3 days long and include both structured time for learning new skills and unstructured time to allow students, post-doctoral scientists, and faculty to get to know each other (Figure 1). The 2013 (year 3) retreat was held at the University of Idaho and included sessions on interdisciplinary data analysis and cross-disciplinary communication, in addition to time set aside for students to explore interdisciplinary collaborative projects (Figure 2). Highlights of this year's retreat, based on student feedback, were the seminar "Climate Change in the Interior Pacific Northwest," delivered by REACCH principal investigator Dr. John Abatzoglou, and opportunities for students to collaborate with one another. Annual graduate student retreats will continue during each year of the REACCH project. The goals and activities, however, likely will morph to meet student needs as they progress in their programs.

Figure 1. *Graduate students, post-docs and faculty gather during a REACCH retreat. Retreats are designed to encourage integration and a sense of community among graduate students working at different campuses. Photo by Erin Corwin.*

A second form of interdisciplinary training within REACCH is use of the Toolbox survey and workshop, an approach designed to help collaborative teams achieve effective communication. The Toolbox instruments and workshop facilitate discussion of research assumptions and how they differ across a collaborative team. Based on more than 100 Toolbox workshops conducted nationally and internationally, these workshops are proven to improve mutual

Table 1. *Part of the rubric developed to help graduate students meet the requirements of REACCH extension and education products.*

Extension or education product rubric	Does not meet expectation	Meets expectation	Exceeds expectation
Multidisciplinary teams	Works alone or with team members within same objective and discipline	Collaborates with an additional student outside of discipline	Collaborates with students and faculty from several disciplines and objectives
Product addresses a need in the Pacific Northwest community	Product does not directly address an identified community need or REACCH objective	Product relates to a perceived need within the stakeholder community and is directly related to at least one REACCH objective	Product relates to a documented need within the stakeholder community as assessed (formally or informally) by students
Ability to translate scientific data to multiple stakeholder communities	Product is written with scientific jargon and content-specific language that is not accessible to a lay audience	Product is written or presented with lay language and visuals; some expert interpretation may be necessary	Product is written or presented with lay language and visuals and can be utilized without the support or expertise of students or faculty

Figure 2. *Graduate students Nevin Lawrence, Taylor Beard, and Isaac Madsen discuss the farming program AgTools™ with senior Matt Miller. Photo by Laurie Houston.*

understanding and self awareness in ways that may significantly enhance collaboration efforts. REACCH students participated in a workshop at our student retreat in 2012 and completed a follow-up online survey in 2013. Results were explored to help students learn about the diversity of views within the project. Student views were compared with faculty views based on a separate faculty survey conducted during spring 2013. Additional follow-ups using the Toolbox are planned as part of our 2014 annual meeting.

To help REACCH students develop their interdisciplinary collaboration skills, each is required to work as part of a team to develop interdisciplinary projects that address the goals of REACCH. These projects must include two or more students from different disciplines working on an extension or education product that can be used by farmers, teachers, students, or other stakeholder groups. A rubric developed to help students meet the project requirements is shown in Table 1.

Eight projects are underway, five focusing on secondary education and three focusing on extension. Extension projects include: video demonstrations of environmental and management effects on crop development; fact sheets describing plant pathogen, soil, and host plant interactions; and interpretation of climatic model outputs. Examples of education projects include: lectures and demonstrations for using GIS and other modeling tools, as well as classroom demonstrations of water infiltration and erosion (Figure 3) for use in a secondary science classroom. All of these projects are described in more detail on the graduate education page of the REACCH website.

Figure 3. *As part of their interdisciplinary education product, REACCH graduate students Chelsea Walsh (soil science) and Hilary Donlon (agricultural economics) demonstrate to teachers a method to model soil infiltration and erosion using inexpensive materials. Materials were distributed to teachers attending the 2013 REACCH teacher workshop and will be available on the REACCH website for others to download. The teacher materials include information on soils, water, erosion, and the economic costs of soil loss. Photo by Brad Stokes.*

REACCH Triptych: Bringing art to science

Liz Allen (lizb.allen@email.wsu.edu) WSU and Isaac Madsen WSU

Like many good stories, the story of how a team of researchers came to create a series of colorful paintings addressing complex issues connected to their research began during a brainstorming session at the REACCH graduate student retreat in Sandpoint, Idaho. We were reflecting on the challenges of communicating science across disciplinary and professional boundaries. We began by sketching conceptual paintings that depicted climate change and agriculture in the Pacific Northwest. We came up with silly and inventive ways to show connections between fields and cities, ivory tower academics and farmers, entomology and cartography, land and air, and science and policy.

After a few more spontaneous meetings, the specific vision for a collaborative art project took shape. We wanted to reflect the truth that in order to address relationships between society and natural resources, multiple perspectives must be engaged. Working collaboratively to produce a work of art struck us as a novel and interesting way for the REACCH research team to explore diverse approaches to understanding climate change impacts on regional agriculture. We envisioned the painting project as a forum for the group to share attitudes about modeling, experimental methods, decision making, and cycles of production and consumption. A key motivation for us, as graduate students interested in a range of social science and natural science questions, was to facilitate working relationships that spanned disciplines—in other words, to promote project integration.

Mulling over the goals and challenges of the REACCH project, three themes emerged that we wanted to explore further: (1) strategic vs. tactical decision making, (2) models vs. reality, and (3) global connectivity. Identifying three themes was fitting, as it allowed us to plan for a triptych, or three-panelled painting, in the tradition of great masters from the Gothic period onward. Walking a fine line between dictating the form and content of the paintings and starting absolute chaos with hundreds of paint trays and brushes, we laid down some rough outlines and penned a prompt for each of the three panels. The outer two panels are focused on perspectives, or ways of understanding the world. The center panel is a representation of interconnections. We shared

IMPACT

Working together on a creative project fostered conversations and greater understanding among our REACCH team about big-picture goals of seeking to understand climatic and philosophical questions embedded in their work. By representing REACCH through art, we have opened new audiences and venues to highlight our work, thus increasing public awareness of the complexities of climate change and sustainable agriculture. We are scheduling showings in various art galleries, and the pieces have been displayed at the U.S. Department of Agriculture, National Institute of Food and Agriculture headquarters in Washington, DC.

Figure 1. Perspective: Models are not reality
The left panel represents tensions between a simplified, abstracted representation in which different conditions and scenarios can be tested (a model) and an organic, complex, multi-faceted reality. Models allow us to see how nature and society operate—yet, they may lead us to overlook the true dynamic nature of the systems we want to understand. There is a challenge for diverse communities to understand and use model outputs; their real concerns and needs are not always well served by models developed in academia. This tension is visualized as a "model world" that fades into a "real and messy" nature. Photo by Joe Pallen.

Figure 2. Web of interconnection: Eating to live
The center panel of the triptych displays relationships between production and consumption, exploring what the concept of sustainability really means. The image is a diagram of a food production system with the cycle's externalities explored. We sought to address the relationships between farmers and consumers, technological change and environmental impacts, policy decisions and food security. Food production is inextricably bound with environmental change. We envisioned the REACCH hovering within the network of connections, with potential to enhance regional carbon storage and address the impacts of nitrate leaching out of agricultural systems. Photo by Joe Pallen.

these painting prompts with the research team of more than 80 faculty, students, and stakeholders at the second annual REACCH Meeting in Portland, Oregon, in February 2013. Then we encouraged, cajoled, and pestered the crowd until more than half of the group contributed to the three 3' x3' canvasses we had laid out with an ample supply of acrylic paints in the hotel lobby.

Thus, the REACCH triptych's story spans three states—Idaho, Washington, and Oregon—just like the interdisciplinary research effort that spawned it. The triptych itself is an integration of art and science (Figures 1–3). Viewing the colorful finished products, we're proud of the work that this team created, but not because of esthetic outputs alone. From our perspective, working together on a creative project fostered conversations and greater understanding among researchers about big-picture goals of seeking to understand climatic and philosophical questions embedded in their work.

Figure 3. Perspective: Scalability of decisions
The right panel explores how academics, policy makers, and farmers think about uncertainty, risk, change, and decision making. Often, people in academia or policy roles are trained to think strategically, looking at how to engineer social and environmental systems to meet a defined objective. In climate change research, this often means taking a global view of change and focusing energy on how to create policy conditions and mitigate greenhouse gas emissions. Farmers and many other actors in society must be tactical decision makers; they must respond to conditions and adapt to local change. The kind of information they need is more refined in terms of spatial scale, and there is inherent risk and uncertainty in their decision-making processes. This image illustrates tensions and overlap between these modes of decision making. Photo by Joe Pallen.

Social network analysis: Finding new insights and opportunities

David Meyer (david.meyer.email@gmail.com) BSU

Have you ever heard the 1972 hit "Lean on Me" with the lyrics "You just call on me brother/When you need a hand/We all need somebody to lean on"? REACCH is a complex project with many potential, necessary, and desirable connections among our team members and stakeholders. The song reminds us to call on friends and family when times are tough—or when we need a sympathetic ear to work through a problem. Our social network can help us in times of need.

IMPACT

Identifying and improving upon collaborations among the 200+ REACCH team members will improve our insights, our opportunities, and the quality and scope of our outcomes. Given this diversity, size, and scope, the coordination of our efforts might be just as important as the individual actors involved. Collaboration will improve both our science and overall management of this complex project.

In this sense, a social network refers not just to relationships on social media such as Facebook or Twitter, but also to the important personal, professional, and community relationships we all enjoy. Being connected with others can have a big impact on our sense of well being and keep us open to new insights, opportunities, and outcomes.

One integration activity used by REACCH this year was a social network analysis to make our social network more visible. The results help us see who connects to whom and can help REACCH collaborators find the right person to "lean on" when needed. In a collaborative effort such as REACCH—one that includes research, extension, and kindergarten through graduate school education—there are more than 200 possible collaborators. Given this diversity, size, and scope, the coordination of our efforts might be just as important as the individual actors involved.

One way to understand the power of social network analysis is to imagine trying to coordinate 200 Facebook "friends" to do some task in which every person has some knowledge, ability, or resource required for success. The relationship between these 200 people would vary; some would be close professional colleagues, while others wouldn't know each other at all. Holding a face-to-face meeting would help, but the team would still spend a lot of time figuring out what contribution each person brought to the task. This kind of team coordination challenge is common to many "team science" efforts, in which a scientific challenge requires the collaboration of investigators with diverse skills and knowledge, such as cancer research and prevention, biomedical technologies, or climate change. Social network analysis gives us a powerful tool to help coordinate our efforts.

Our social network analysis started in the winter of 2013, when everyone participating on the project (including researchers, graduate students, stakeholder advisory committee members, scientific advisory panel members, and others) was asked about his or her collaborations on the project during the previous year. Response choices ranged across five levels of collaboration from "I don't know this person" to "a strong integration of ideas, merging of perspectives, and growth of common understanding...a new understanding based on what we both brought to the task." The survey feedback gives a sense of how 212 people across the entire range of REACCH activities are working together.

But simply having a graph of who is collaborating with whom does not tell us much about how to improve the project. Social network analysis software gives us the ability to combine these survey results with other information such as the individual's discipline, REACCH activity area, role in the REACCH project, and other grouping characteristics. Rather than a web of individual actors, we can map the interactions among disciplines, activities, or institutions and better see the "big picture" of REACCH collaboration.

The results illustrate two important social network concepts: degree centrality and brokerage. Degree centrality is the count of the number of strong collaborations among individuals (Figure 1). Degree centrality is like a popularity ranking; people with high degree centrality scores are more likely to be key conduits of information, opinion leaders, and early adopters of new knowledge or practices active in the network. Degree centrality of REACCH collaborations helps show the individuals, disciplines, or activities that have the highest number of strong collaborations. This information can be used to help manage workload and identify people, activity areas, or roles that need more support.

Brokerage or "betweenness centrality" measures the shortest path between people. The "brokerage" term fits our real-world use of the word too; just like a real estate, mortgage, or pawn broker, these people help connect individuals and groups who otherwise would have a very limited relationship. Betweenness centrality measures an actor's position within a network in terms of his or her ability to make connections to other pairs or groups in a network.

One way to understand betweenness centrality is to imagine a highway map of the United States. Cities with high degree centrality would include New York and Los Angeles, which have many roads to nearby communities. A city in the middle of the country, such as St. Louis, would have lower degree centrality (fewer roads going in and out of town), but high betweenness centrality because it lies on the shortest path between many cit-

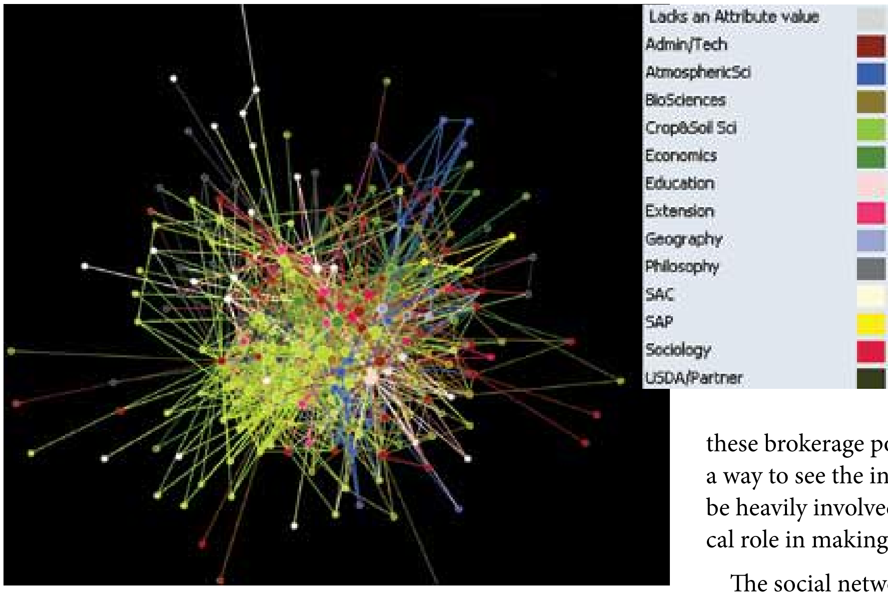

Figure 1. *This social network graph shows the individuals who report high levels of collaboration with others on the REACCH project. Larger circles that are closer to the center of the graph are people with higher "degree centrality" and indicate people who have a higher number of collaborative relationships across the project. The circle and line colors show the primary academic discipline of each person. REACCH team members can use graphs like these to illustrate collaboration across individuals, disciplines, institutions, or activity areas. (Names have been removed from this graph for privacy.)*

ies on the east and west coasts. St. Louis may not be "popular" like the large, well connected east coast cities, but its position in the middle of the country makes it very important if you want to connect the east and west coast.

In the REACCH collaboration survey, individuals with high betweenness centrality may or may not be the most "popular" collaborators (as measured by degree centrality) but they play a vital project role because they collaborate with other people or groups who are less connected with each other. Making these brokerage positions more visible gives the REACCH team a way to see the individuals, disciplines, or activities that may not be heavily involved in the project as a whole, yet may play a critical role in making the right connections across the team.

The social network analysis effort started this year is just one way the REACCH team has improved collaboration across researchers, students, activity areas, and stakeholder groups. Combined with other efforts this year, including our annual improvement survey, an inventory of graduate students' philosophical commonalities and differences, outreach workshops, biweekly project integration meetings, and more, the REACCH team continues to find better ways to manage collaborative team science projects (Figure 2).

Figure 2. *REACCH team members mix it up with each other, members of our Scientific Advisory Panel and Stakeholder Advisory Committee, members of the Corn CAP and PINEMAP, and the REACCH band at the 2012 annual meeting. Photos by Laurie Houston.*

The REACCH data management system

Erich Seamon (erichs@uidaho.edu) UI, Paul Gessler UI, and Sanford Eigenbrode UI

The REACCH Data Management System is a "behind-the-scenes" collection of information technology tools (e.g., servers, networking hardware, database software, web portal and interface software, and people) organized to help researchers and stakeholders store and archive data, explore and discover data, and integrate data sets for collaborative research. It is designed to be secure, expandable, and flexible. In partnership with the Northwest Knowledge Network (NKN) at UI we are working to preserve preserve the data and analysis applications for the life of the REACCH project and beyond. The data and developed applications will be an important legacy of the REACCH project that will be accessible via our collaborating institutions and national repositories.

IMPACT

The REACCH data management system is a "behind-the-scenes" collection of information technology tools (e.g., servers, networking hardware, database software, web portal and interface software, and people) organized to help researchers and stakeholders store and archive data, explore and discover data, and integrate data sets for collaborative research.

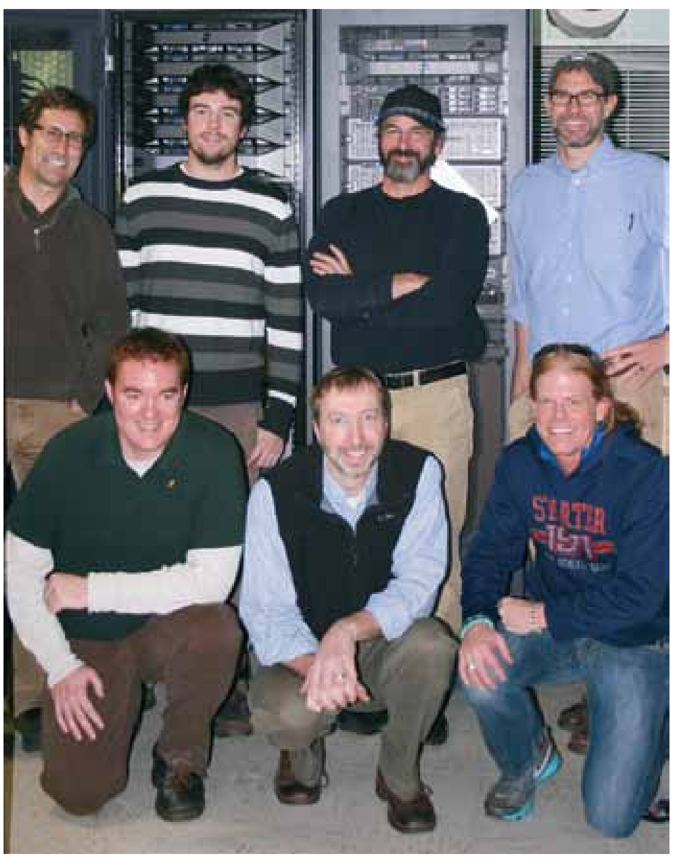

Figure 1. *Members of the REACCH cyberinfrastructure and NKN personnel in front of enterprise servers: back row from left: Paul Gessler, Stephen Fricke, David Vollmer, Luke Sheneman. Front row from left: Ed Flathers, Bruce Godfrey, Erich Seamon. Photo by Brad Stokes.*

The integration of these tools and technologies is critical to our project success. Most of the REACCH research teams are collecting data using a wide variety of methods and formats. With a diverse number of research locations and types of data, the integration of such information to facilitate useful decision making is an important challenge.

To address this challenge, the REACCH Data Management and Cyberinfrastructure team (Figure 1) has developed and implemented a technology strategy focuses on three core areas:

- Data management, harvesting, and ingestion through a central web portal. Our www.reacchpna.org web portal is a central point for both public and secure information access, where users can search for and analyze data. Our REACCH Data Library, accessible via www.reacchpna.org, uses technology that allows us to upload or harvest data from a variety of sources and then allow those data to be searchable.
- Data meta-tagging and transformation. Our data management efforts have focused strongly on ensuring that the description of data is complete. This helps ensure that the data are easily discoverable using web search tools and that the data can be used indefinitely.
- Data exposure and consumption. With data stored and exposed using standard web protocols, we can make the data available in a variety of ways so that users can download or link to the data for use in a wide variety of applications and modes. Advantages include the ability to dynamically link to the data from within specific applications without having to download the data (Figure 2).

Access to REACCH data can be grouped into two areas: the REACCH Data Library and the REACCH Analysis Library. Accessible from the www.reacchpna.org portal, the Data Library and the Analysis Library provide clear and straightforward mechanisms to upload, search for, and analyze REACCH-based data.

The REACCH Data Library provides access to raw data, publications, presentations, images, and other content that may be REACCH project related. By meta-tagging each data set and research product, we can see relationships between data and products and allow users to explore how data and publications are interconnected.

The REACCH Analysis Library allows users to examine data within the REACCH Data Library for research-related functions, agriculture-based decision making, education, and other stakeholder needs. Some of the tools currently being developed for the

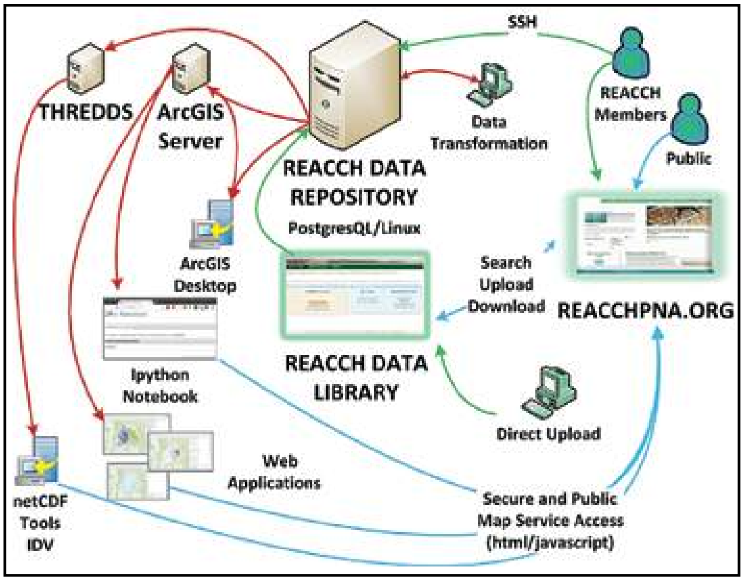

Figure 2. *The REACCH technology architecture focuses on harvesting, meta-tagging, and then integrating data through the use of geographically based web service protocols.*

REACCH Analysis Library includes the following:

- Inland Northwest growing degree calculator
- Climatic model data aggregation and filtering
- Inland Pacific Northwest biotic data examination
- Agroecozone geospatial model development
- Interrogation of data using interactive programming tools such as Python™

Figure 3. *REACCH students participating in a data management course in August 2013. Photo by Brad Stokes.*

Visualization and analysis using REACCH data analysis tools

Erich Seamon (erichs@uidaho.edu) UI, Paul Gessler UI, and Sanford Eigenbrode UI

An important component of the REACCH technology system is the development of analytical tools that enable researchers, as well as the public, to organize and examine REACCH data in effective and useful ways. Our tool development is focusing on the use of web services to expose, organize, analyze, and present REACCH data in ways that support stakeholder analysis and decision making. Web services allow users to connect to data for analysis and visualization via a web browser without downloading the data to a local computer, thereby making the data more dynamic and accessible to a diversity of users.

IMPACT

These data analysis tools will allow REACCH researchers and educators to effectively use and analyze complicated data sets. Growers and the agricultural industry will have the best information available to make sustainable management decisions in the face of changing climatic conditions.

Our tool development efforts can be divided into four functional areas:

- **Web browser-based analytic tools:** Building on our data cataloging and meta-tagging model, we are currently developing several map-based applications, including the following:
  - Climatic data viewing, analysis, and download (Figure 1). Using our REACCH climatic data viewer, users can build their own request for particular climate model output, based on a location or time period.
  - Growing degree calculators for the Pacific Northwest. Using our REACCH biotics data viewer, users can determine the average number of growing degree days for a particular crop and location.
  - Soil and topography data viewers, which use an organization of Natural Resources Conservation Service and U.S. Geological Survey data.
- **Meteorological and climatic modeling data aggregation:** Our REACCH modeling framework team has produced more than 15 terabytes of meteorological and climatic model data outputs. With such large data sets, we have implemented a data aggregation technology that allows anyone to aggregate and download data based on geography, time, or a particular variable (http://thredds.reacchpna.org).
- **Use of Interactive Python for researcher data analysis:** Interactive Python (IPython) is a web server-based technology that allows users to create "research notebooks" for collaboration around Python-based data interrogation.
- **Geospatial analysis using ArcGIS:** A key component of our analysis tools enables geographic analysis and visualization (Figure 2). As such, all data that are uploaded to our REACCH Data Library are loaded into our geospatial database, which can then be searched, analyzed, and visualized using ArcGIS Desktop in a variety of ways.

In support of the above, the REACCH Cyberinfrastructure team has developed a series of geospatial short course videos to educate students and other REACCH team members on the use of ArcGIS to examine REACCH data. These short courses also explain how to develop geospatial data models that might incorporate REACCH data.

The tools and data access methods described here are all part of the cyberinfrastructure and data management strategy to help both researchers and broader stakeholders gain access to the valuable data sets being collected and organized by the entire REACCH team (Figure 3).

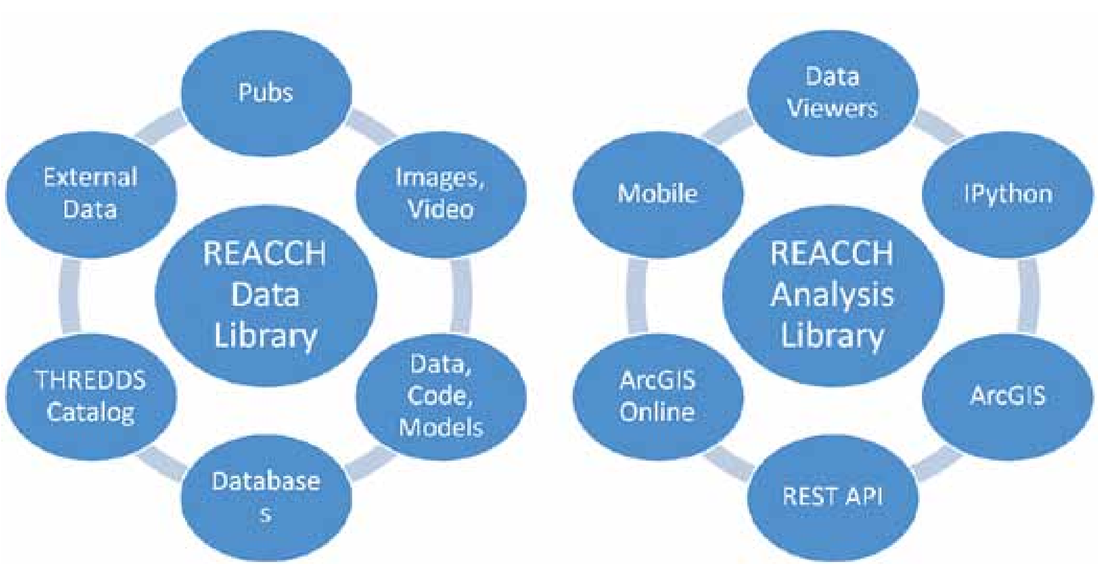

Figure 1. *Flow diagram of REACCH Data Library and Analysis Library.*

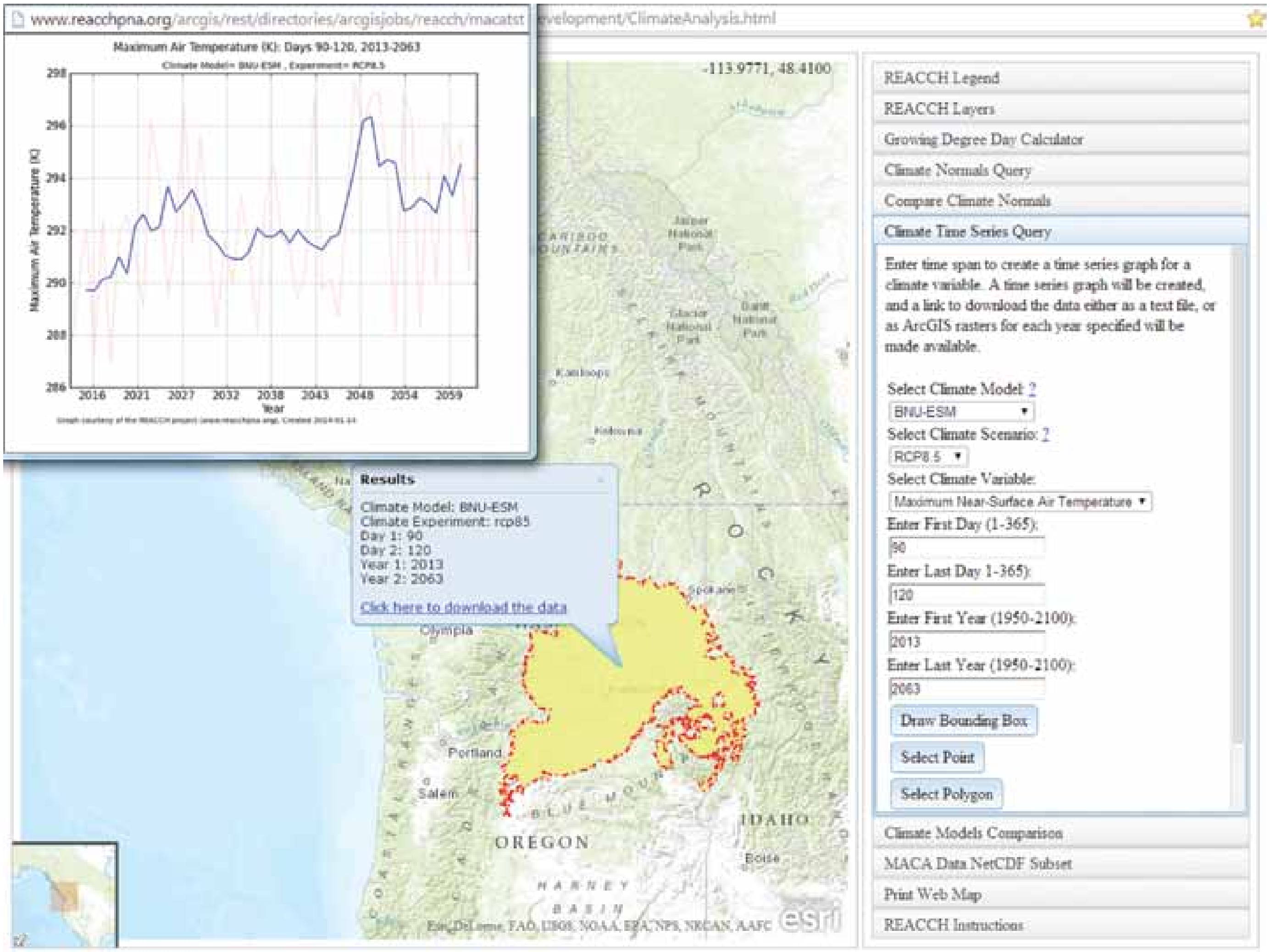

Figure 2. *Example of a web-based geographic analysis using REACCH tools—examining maximum April–June air temperature changes for the REACCH study area (1970–2000).*

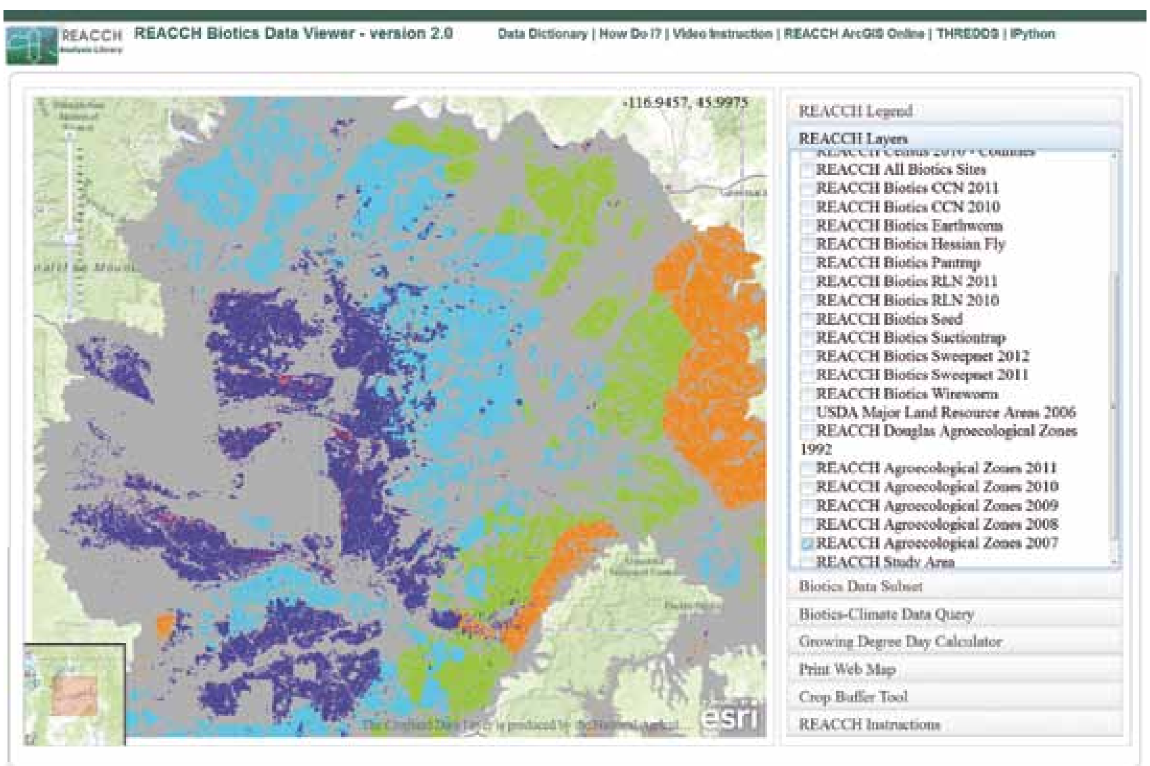

Figure 3. *REACCH Climate Viewer with agroecozones (AEZ) for the Pacific Northwest study area.*

Training the next generation of scientists

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Sustained or increased food production under projected climate change is a principal challenge facing human society. Future scientists must gain cross-disciplinary research skills to effectively address this challenge and contribute to the solution. The unique interdisciplinary foundation provided by REACCH allows undergraduate interns to gain hands-on training in research. The overall goals of the REACCH internship project are to:

- Involve undergraduates, especially those with little opportunity to undertake independent research at their home institutions, in cutting-edge, cross-disciplinary research related to climate change adaptation and mitigation in managed ecosystems
- Improve the ability of students to communicate across disciplines
- Increase student knowledge and interest in graduate school and science, technology, engineering, and mathematics (STEM) careers.

IMPACT

Participating in cross-disciplinary, hands-on training away from their home university can give undergraduate students new perspectives by allowing them to have unique research experiences, collaborate with multiple people from various backgrounds, and experience new locations. These opportunities can enrich undergraduate learning beyond traditional university experiences and better prepare them for future education and career opportunities.

A total of 64 students applied for the REACCH 2013 summer internship program. Following review of the applications and interviews, 15 of the 64 applicants were asked to participate in the internship. Five students were funded by REACCH at each campus. An additional student was recruited at the University of Idaho utilizing funding from the University Experimental Program to Stimulate Competitive Research (EPSCoR) office. Our final group of 16 interns came from institutions ranging from small, private colleges to large research universities across the United States (Oregon to Maine). Approximately 56% of the students were female, and 25% were ethnic minorities.

Students teamed with faculty mentors to complete a research project over the 9-week internship. Students tackled diverse topics, from determining carbon mineralization rates in different cropping systems to assessing farmers' decision-making processes (Table 1). Each student presented his or her research at a final research symposium held on the University of Idaho campus. In addition, three REACCH interns were able to present their work at a regional climate science conference in Portland, Oregon, after

Table 1. *Summer intern research projects.*

Institution	Research topic
WSU	Analysis of carbon mineralization on rates among diverse farming systems to determine soil health
WSU	Long-term effects of biosolids on carbon sequestration
UI	Weed management from present to future assessing wheat producer and crop advisor decision-making strategies
UI	Effects of climate change on the biological control of cereal leaf beetle
OSU Pendleton	Generating water characteristic curves of soils
OSU	Government policy on climate change
UI/WSU	Effects of climate change on cropping systems in the Palouse
WSU	Impacts of drought and pest community on wheat
WSU	Mayweed chamomile
UI	Prevented planting policy in a highly erodible area
UI	Online hydrologic modeling of agricultural erosion
OSU	Next-generation climate scenarios of ClimatePrediction.net
UI	Earthworm density and soil property relationships in the Pacific Northwest region
UI	Climate controls of earthworm activity and aestivation in agroecological zones of the inland Pacific Northwest
OSU	Toward AgEnvironment
OSU	Toward AgEnvironment

Figure 1. *REACCH 2013 summer interns at the end-of-the-summer research symposium held at the University of Idaho. Photo by Marijka Haverhals.*

REACCH intern Joanna Parkman presents her summer research at the 2013 Pacific Northwest Climate Science Conference held in Portland, Oregon. Photo by Leigh Bernacchi.

Table 2. *Events and workshops offered to REACCH summer interns. Workshops focused on skill development.*

Event title	Purpose
Palouse Prairie field trip	Discussion of the interactions between native and managed systems; provide a landscape-scale understanding of the region
Viewing of Green Fire: Aldo Leopold and a Land Ethic for our Time	Exploration of conservation ethics
Ethics workshop	Discussion and exploration of research ethics
Biocontrol center field trip	Greater knowledge of the principles of biocontrol of pests
How to prepare for graduate school	Discussion of how to find and apply to graduate school; funding mechanisms; professional communication
Toolbox workshop	Exploration of the importance of and challenges associated with cross-disciplinary communication
Final research symposium	Gain experience in summarizing and presenting research and results

the internship ended. The interns' research results helped answer important questions and will move the overall REACCH project forward toward meeting our goals.

In addition to building research skills, REACCH summer interns participated in workshops and activities developed to help provide context to their research and/or to develop specific skill sets (Figure 1). Field trips provided an opportunity for students to gain a more landscape-scale perspective on their research, providing more knowledge of specific topics, such as biocontrol. They also provided time to build community within the group of interns (Table 2).

At the conclusion of the program, interns were asked to complete a survey regarding their research experience. The majority of students (93%) either agreed or strongly agreed that they know how to pursue a career in science. When asked about graduate school, 92% of students agreed that they know how to apply, and 93% agreed or strongly agreed that they know how to prepare. One hundred percent of students agreed or strongly agreed that they were confident in their ability to work in interdisciplinary teams. One hundred percent of students responding also agreed or strongly agreed that they can communicate their area of interest to someone in another field. When asked to list the two or three most important things gained from the internship experience, the most common response was "actual research experience (six students). Four students mentioned that the program helped them learn about their skills and helped refine future plans. Three students mentioned how to apply for graduate school.

When asked whether anything was lacking from the experience, five students responded with "no." Other students made great suggestions that can easily be implemented in the 2014 internship program. These suggestions included greater interaction with project stakeholders outside of the university, more discussion with faculty on why they chose to go into their specific fields and go to graduate school, and more field trips and emphasis on science careers.

REACCH 2013 summer intern Heath Hewett samples for earthworms in a grower-collaborator's field. Photo by Chelsea Walsh.

Agriculture and climate change education in K–12 classrooms

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Greater inclusion of agricultural topics, including climate change issues, in secondary and elementary classrooms is a key objective of the REACCH program and is vital to the future of the agriculture industry. Identifying the status of agriculture and climate change instruction in K–12 schools throughout the region was one of the first priorities of our outreach efforts. Figure 1 shows the frequency of agriculture-related instruction in the REACCH study region. Nearly 1,600 public school teachers representing grades K–12 from across the study region provided this information. The importance of reaching students early and often cannot be over-emphasized, yet in most elementary and secondary classrooms, instruction about agriculture occurs once a month or less.

IMPACT

Supporting educators with materials and knowledge to teach agriculture and climate change science can facilitate greater exposure to these subjects in K–12 classrooms.

The teachers at both elementary and secondary levels agreed that agricultural topics would enhance their curriculum and that integration should occur at all grade levels. They also agreed that a basic knowledge of agriculture and climate change issues was important for students to be able to make socially responsible and healthy decisions on a daily basis (Figure 2).

Given the results of the survey, the REACCH education team developed a high-school-level curriculum based on REACCH research areas. The curriculum can be a semester-long course, or individual units can be used in science or agriculture classes. The activities, technical scientific readings, and instructional presentations were aligned with national and state standards. The curriculum is intended to be user friendly for teachers, as they indicated in the study that they lack the time to prepare additional curriculum including agriculture and climate change.

REACCH in-service teacher monitoring carbon dioxide production in seeds. Photo by Kathryn Bonzo.

In summer 2013, 19 teachers from Oregon, Washington, and Idaho came to Moscow, Idaho to participate in the second annual REACCH teacher in-service. To bridge another gap identified by teachers (cost of materials), specialized laboratory equipment was given to participants. This equipment included digital carbon dioxide and temperature sensors, software, computer interfaces, and basic laboratory supplies. The equipment will provide teachers with avenues to teach agricultural science concepts through hands-on activities.

This summer's content focused on soil and water, with units designed to explore soil basics, soil erosion, and the carbon cycle.

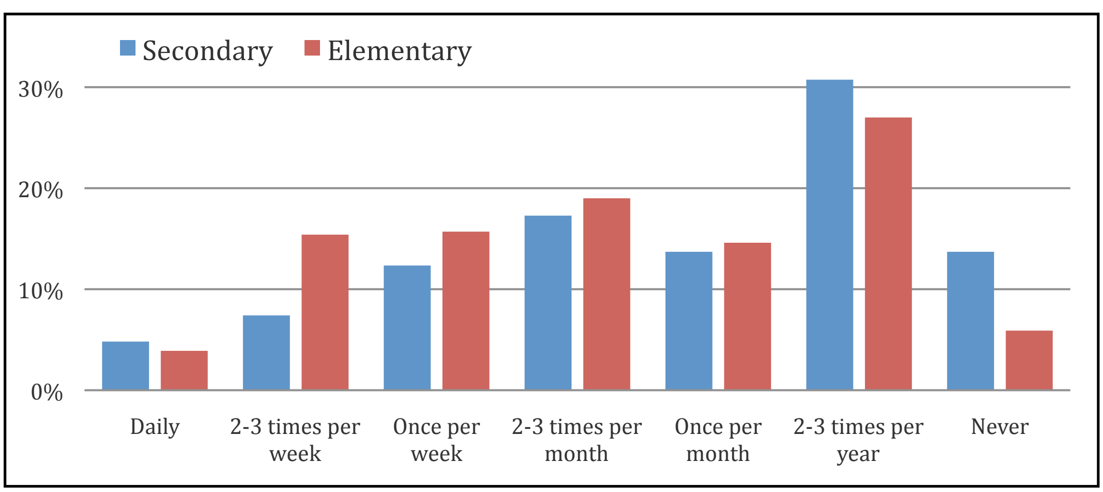

Figure 1. *Average frequency of inclusion of agriculture in the curriculum.*

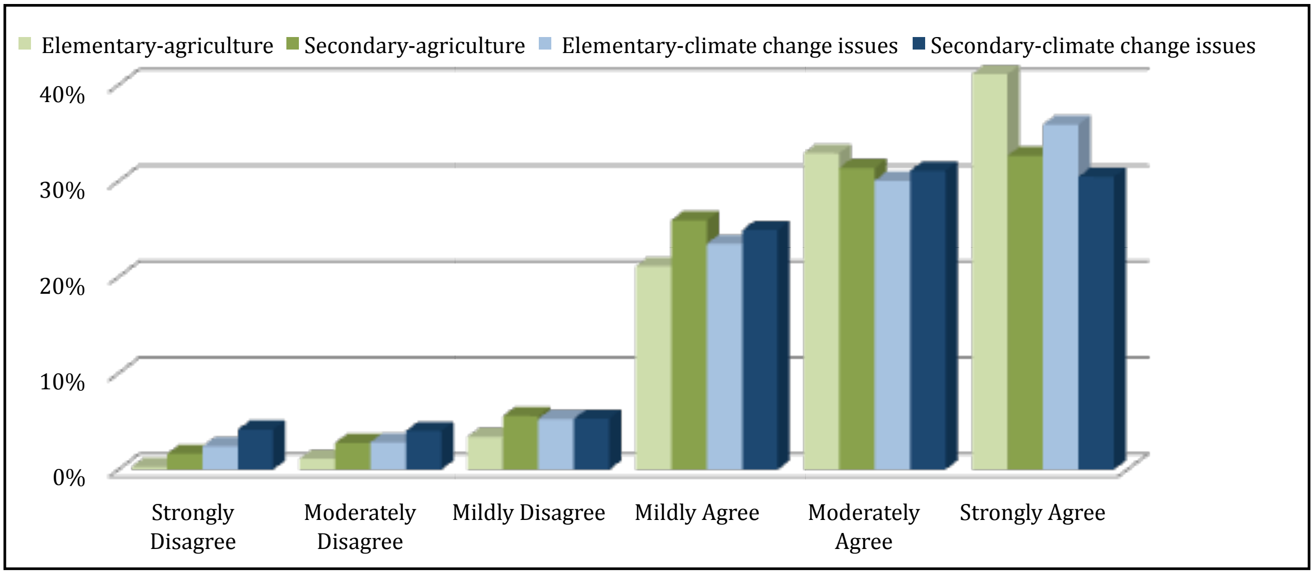

Figure 2. *Importance of a basic knowledge of agriculture and climate change to students as perceived by teachers.*

Through hands-on exploration, students can see the effects of photosynthesis and respiration, and can model the greenhouse effect on a small scale. These activities teach not only the scientific principles needed to understand climate change, but also allow students to explore the scientific process, explore model limitations, and understand that scientific knowledge is ever evolving based on new information.

Teachers across the nation are charged with adopting the new Common Core State Standards. Early adoption efforts focus on mathematics and language arts; for science and agriculture teachers this means adding technical reading to their classes, student speeches, and presenting data in group settings. To aid teachers, the REACCH curriculum included readings at varying levels for teachers to incorporate into their classroom. Where possible, these documents were produced by REACCH scientists. As the project advances, more project-based articles will become available to augment these initial readings.

Teacher workshop participants agreed to teach the units in the 2013–2014 school year. They began by administering both a knowledge and attitudinal questionnaire to the students. Attitudinal surveys asked students about their perceptions of climate change and its perceived impact on them personally. Knowledge of individual parts of the curriculum, as measured by the difference in pre- and post-knowledge questions, will gauge the effectiveness of the curriculum. Following the piloting of the units, teachers will discuss the curriculum, its effectiveness, and problems they encountered while implementing it. The resulting curriculum will be better adapted to meet the needs of students in the region.

Teachers collecting soil samples from different horizons to display for classroom use. Photo by Kathryn Bonzo.

The future and broader impacts of REACCH

Sanford Eigenbrode (sanforde@uidaho.edu) UI

Where are we going with the REACCH project?

To understand the long-term vision for REACCH requires taking a look at our roots. For nearly 3 decades, the Solutions To Environmental and Economic Problems (STEEP) program benefited the region's agricultural industry through targeted applied research and extension to address the productivity and sustainability of our systems. In part, REACCH aims to continue this tradition, but with two important differences: (1) unprecedented greater collaboration among scientists, students, and extension personnel addressing diverse aspects of our wheat production systems, so that many small projects function effectively as a single coordinated whole, and (2) having the goal of establishing a collaborative framework and research effort that is sustained beyond the term of REACCH funding. This vision has inspired our core group of principal investigators since we first began meeting in 2009 to develop the concept for a long-term agricultural project for the inland Pacific Northwest.

IMPACT

The collaborative framework developed by REACCH will do the following:

- Enable more fully integrated, long-term research among disciplines and institutions in the inland Pacific Northwest.
- Facilitate training new generations of scientists capable of addressing complex problems facing agriculture.
- Establish approaches to involve stakeholders fully in these activities going forward.
- Contribute to enhanced sustainability of agricultural ecosystems in the inland Pacific Northwest.

In February 2016, REACCH as a formal entity will be no more, but our aim is to have established the foundation for a regional project capable of addressing the following:

- Understanding how agricultural system components interact at larger scales (e.g., region, watershed, landscape)
- Anticipating the environmental effects of shifting agricultural practices
- Improving the effectiveness of conservation programs
- Responding to climate variability and change
- Identifying the broader societal benefits of modern agriculture (e.g., bio-energy production, carbon sequestration, improved water quality and water use efficiency, wildlife habitat)
- Addressing these issues through transdisciplinary integration involving sciences, social sciences, and humanities
- Training new generations of professionals to function in broadly integrated settings

Figure 1. *The REACCH project will help ensure that future generations in our region will have sustainable agricultural systems. Photo by Jillian Blume.*

- Reaching stakeholders as construed broadly: farmers, rural communities, and other citizens
- Addressing the nexus of agriculture and other sectors mediated through resource requirements, e.g., water resources, transportation sectors, human health, and natural resources conservation
- Ensuring maximum cooperation among land grant institutions, federal agencies, and other regional entities and projects, including the National Science Foundation (NSF) National Ecological Observatory Network (NEON), the Pacific Northwest Climate Science Center, the Long Term Ecological Research sites of the NSF, the Agricultural Research Service (ARS) Long-term Agricultural Research Network (with the newly designated node at Cook Agronomy Farm), the U.S. Department of Agriculture (USDA)-designated Northwest Climate Hub, and ongoing and anticipated single-investigator and collaborative projects at all of our partner institutions.
- Participating in national and international networks of regional projects that are similarly integrated to maximize efficiency and discover and implement the best approaches to sustaining agricultural production nationally and globally.

During year 3 of REACCH, many of our activities are consistent with our vision to build this type of foundation:

- We have worked with and have many cross-collaborative arrangements with other regional projects concerning agriculture, including the BioEarth, Site-specific Climate Friendly

Farming, and Watershed Integrated Systems Dynamics Modeling (WISDM) projects at Washington State University; the developing USDA Long Term Agricultural Research (LTAR) project, which will be situated at Cook Agronomy Farm; and the newly established USDA Climate Hub for the Pacific Northwest. The interactions include planning meetings of the principals of all of these projects for longer term integration, shared modeling platforms, and other types of collaboration. For the second consecutive year, a REACCH principal investigator (Phil Mote) chaired the annual Pacific Northwest Climate Science Conference (Portland, Oregon, 5–6 September 2013), where REACCH students and principal investigators made presentations. The REACCH Objective 8 lead (Paul Gessler) serves on the Northwest Knowledge Network (University of Idaho) advisory team and is leading the development of an Idaho strategic plan for cyberinfrastructure development to support collaborative research.

- Our collaborative sphere is also national and international. Principal investigators Antle and Stöckle are leaders in the Agricultural Models Inter-comparison and Improvement Project (AgMIP), which has resulted in close cooperation with crop modellers from around the world, and has allowed us to test and improve CropSyst and other models for climate change assessment. This activity will result in AgMIP team communications, including journal articles in preparation and one article recently published in Nature Climate Change. REACCH project director Eigenbrode participated in the Southeast Climate Consortium meeting in November 2013. REACCH principal investigators (Mote, Capalbo, and Eigenbrode) contributed to the National Climate Assessment report and a follow-up volume to be published in 2014 by Island Press (A Northwest Climate Report, Mote, Capalbo, Eigenbrode, Johnson-Maynard, and Kruger). Principal investigators contributed to the national Inter-institutional Network for Food, Agriculture and Sustainability (INFAS) collaboration paper on climate change and food security. The project directors and project managers of REACCH and two other National Institute of Food and Agriculture (NIFA) Climate Coordinated Agriculture Projects (CAPs) (Sustainable Corn, Iowa State University leading; PineMap, University of Florida leading) meet regularly, attend one another's annual meetings to exchange ideas and approaches to improve overall effectiveness, and are producing some collaborative outputs, including publications.

As we go forward into year 4 of REACCH, expect to see these kinds of collaborative activities increase and structures to emerge that will ensure continuing research education and extension that address immediate and long-term needs of wheat producers, as well as the agricultural industries and citizens affected by these activities in our region (Figures 1 and 2). As we pursue this overarching goal, we will want to make sure to have appropriate and substantive input from stakeholders, starting with the REACCH Stakeholder Advisory Committee, but soliciting input from others.

If you are reading this, and if you appreciate the importance of the projects described in this annual report and would like to help us establish an impactful legacy for REACCH that continues and builds upon this work and our integrated approach to pursuing it, please contact us! We would love to hear from you.

Figure 2. *Through education, mitigation, adaptation, and participation, REACCH participants are enhancing the future of cereal cropping systems in our region. Photo by Brad Stokes.*

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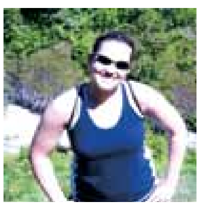

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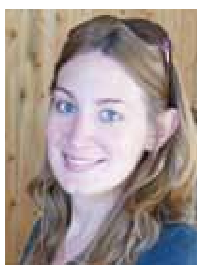

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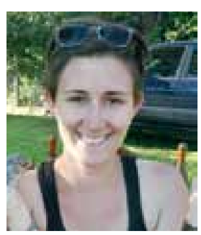

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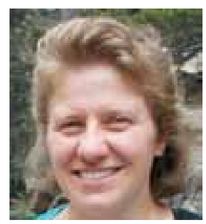

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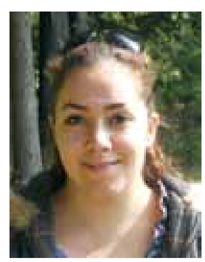

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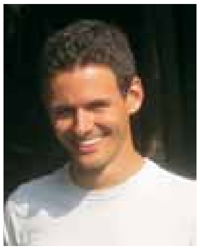

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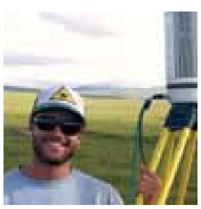

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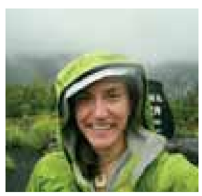

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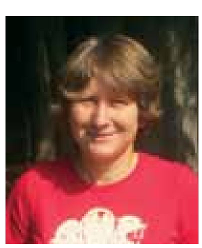

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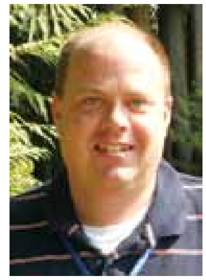

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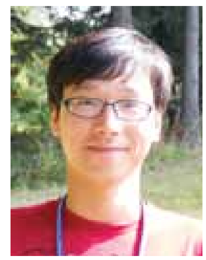

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Further reading, year 3

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www.agclimate.net

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Kruger, C.E. 2012. If climate change may benefit PNW agriculture, are farmers off the hook for reducing greenhouse gas emissions?; Climate change and ag initiatives: can we achieve more than the sum of the parts?; Is organic farming "climate-friendly"?; Are cows really worse for the climate than cars?; Will climate change lead to a food system collapse?

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Links

REACCH website:
https://www.reacchpna.org/

Organization chart:
https://www.reacchpna.org/about-reacch/reacch-org-chart/

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2013 Speed Science videos and reports:
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OutREACCH issues:
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Webinars:
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Blogs:
https://www.AgClimate.net

2011 and 2012 Annual Reports:
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Opportunity for funding—Extension mini-grant:
https://www.reacchpna.org/mission/extension/extension-outreach/extension-funding-opportunities/

Collaborators and partners:
https://www.reacchpna.org/about-reacch/collaborators-and-partners/

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2015 REACCH international meeting:
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Metric conversion table	
From	To
1 hectare (ha)	2.47 acres
1 acre	0.41 ha
1 lb	454 g
1 lb	0.45 kg
1 kg	2.2 lbs
1 ft	0.31 m
1 m	3.3 ft
1 in	2.54 cm

Photo courtesy Stone-Buhr Flour Company.

Foodweb Ethics

Taste of Wind, Water, Sun and Soil
Sensual Celebration of Profound Intimacy
Deep Communion with Earthly Toil
Entwined with Justice, Peace, Love
and Ecstasy

– Dave Huggins

Nature's Wisdom

Plow turns soil, scarring Earth
Organic, mineral exploitation
Earth turns mankind, patient rebirth
Mankind's mistake is Nature's wisdom

– Dave Huggins


REACCH
Regional Approaches
to Climate Change –
PACIFIC NORTHWEST AGRICULTURE

The REACCH project is designed to enhance the sustainability of cereal production systems in the IPNW under ongoing and projected climate change, while contributing to climate change mitigation by reducing emissions of greenhouse gases.

REACCH partners:

University of Idaho

Washington State University

Oregon State University OSU

USDA United States Department of Agriculture

Agricultural Research Service

National Institute of Food and Agriculture

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