Regional Approaches to Climate Change
for Pacific Northwest Agriculture
Climate Science Northwest Farmers Can Use

Project Impacts 2011-2017

REACCH
Regional Approaches to Climate Change –
PACIFIC NORTHWEST AGRICULTURE

www.reacchpna.org

Funded through Award #2011-68002-30191 from USDA National Institute of Food and Agriculture

Contents

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

The REACCH project is an interdisciplinary research effort that was developed across three states (Oregon, Washington, and Idaho), and between four institutions–the University of Idaho, Oregon State University, Washington State University, as well as the USDA Agricultural Research Service (USDA ARS). More information at **reacchpna.org**

Edited by Dianne Daley Laursen, Diane Noel and Amy Pendergraft • Designed by Melissa Rockwood, Rdesign, Moscow ID • Cover photo by Brad Stokes • Back cover photo by Nita Robinson

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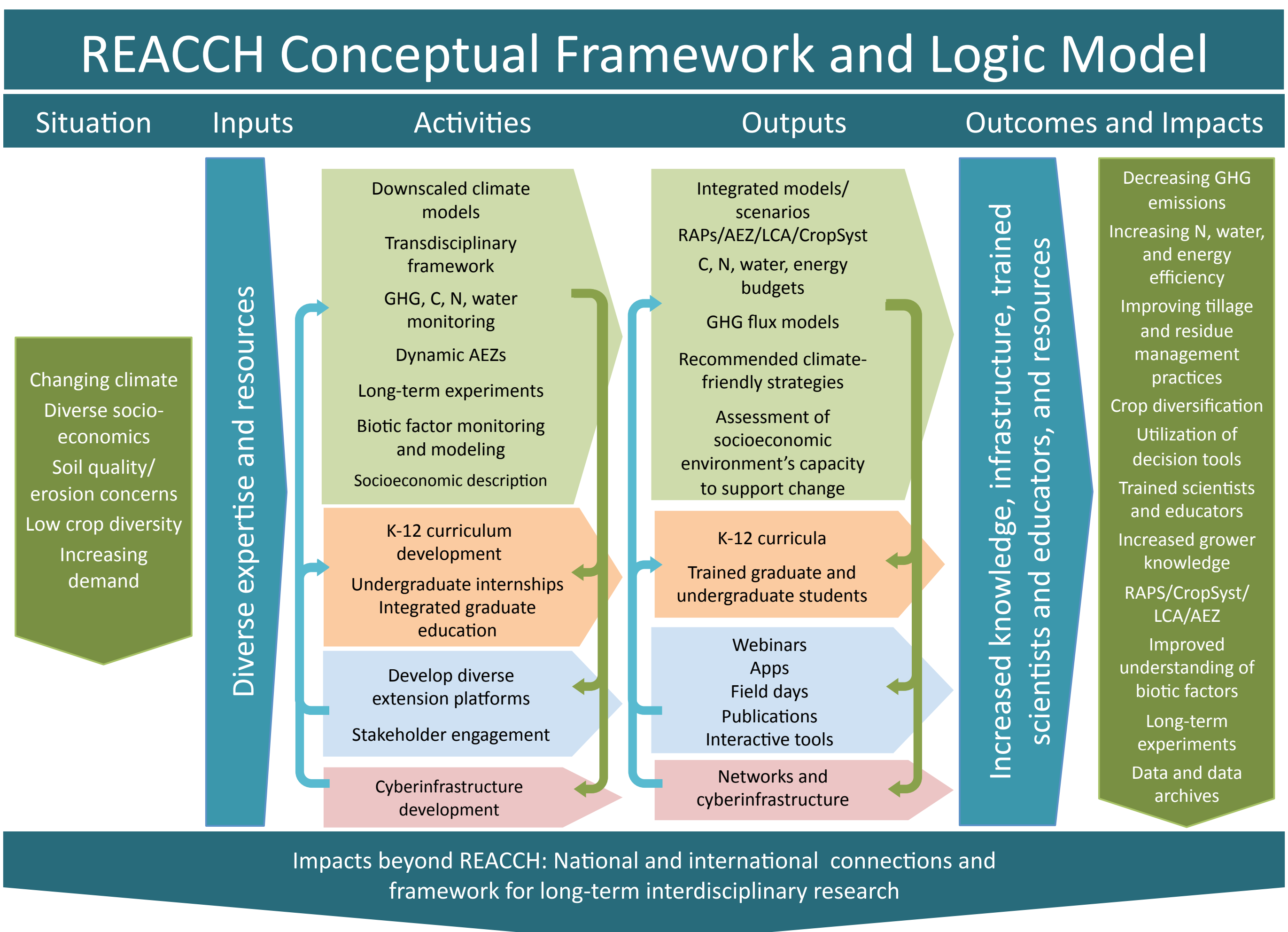
REACCH Project impacts:
Climate science farmers can use

The Regional Approaches to Climate Change for Pacific Northwest Agriculture (REACCH) project is designed to enhance the sustainability of cereal production systems in the inland Pacific Northwest (PNW) under ongoing and projected climate change, while contributing to climate change mitigation by reducing emissions of greenhouse gases. The study area includes northern ID, north-central OR, and eastern WA, the most productive dryland wheat-producing region in the world. The tremendous importance of cereal-based agriculture greatly affects local economies and influences regional culture and communities.

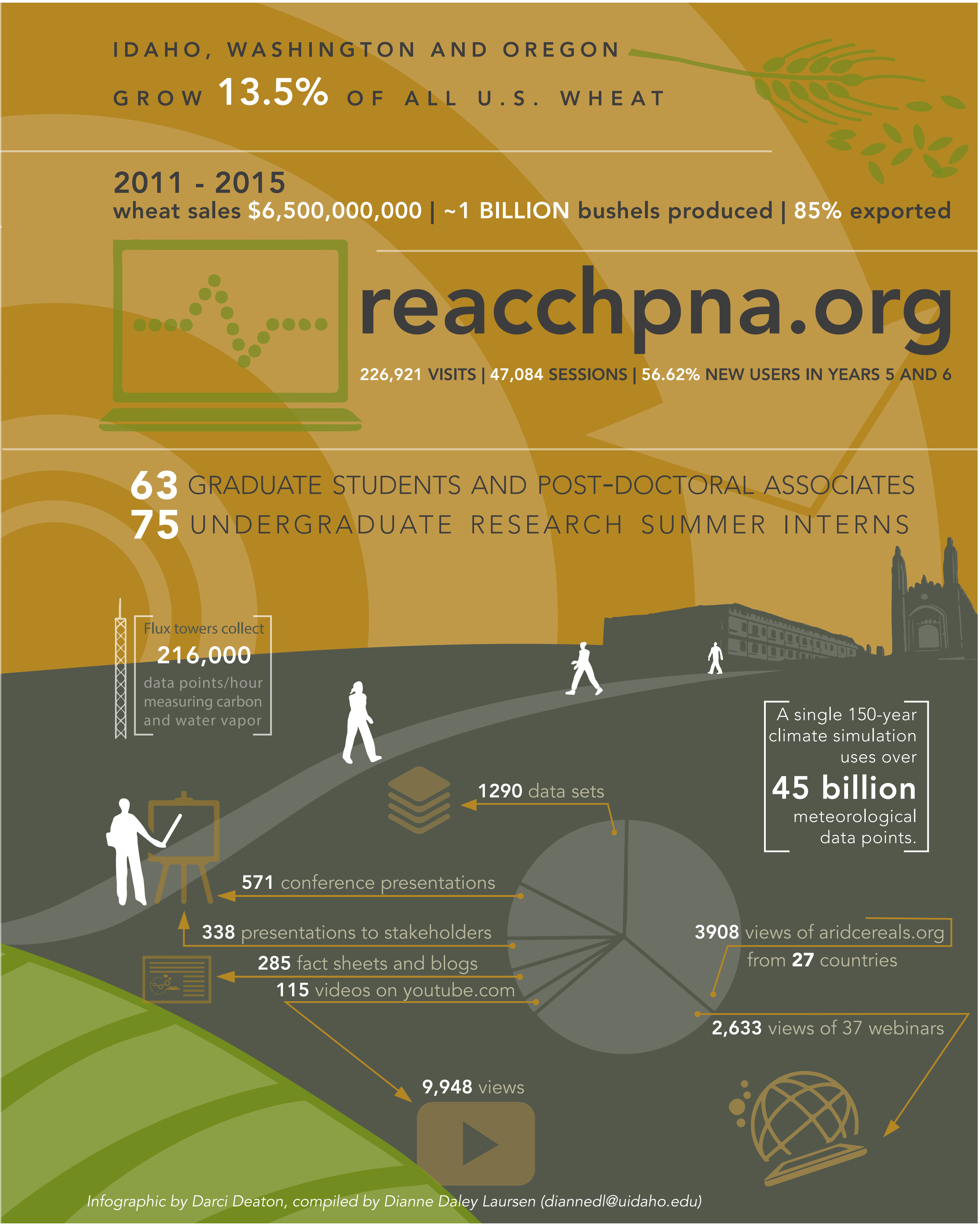
REACCH is a comprehensive response to the implications of climate change for the already challenging task of managing cereal production systems for long-term profitability. Scientists from many disciplines, including engineering, climate science, agronomy, sociology, and economics, work together to ensure greater relevance of the information provided to regional cereal farmers and their associates. Our aim is to conduct the best agricultural science relevant to regional climate projections and the needs for adaptation and mitigation and to extend this science to our diverse group of stakeholders.

The U.S. Department of Agriculture's National Institute of Food and Agriculture (NIFA), which invests in the agricultural sciences to solve societal challenges, funds REACCH. Through the integration of research, education, and extension, REACCH is part of NIFA's mission to ensure innovative solutions to problems in agriculture, food, the environment, and communities that go beyond the laboratory, into the classroom, and to people who can put the knowledge into practice. This book highlights 66 impacts from REACCH, additionally, other impacts and publications will be added to the REACCH website, reacchpna.org. We believe that these impacts provide information useful to our diverse stakeholders, including farmers, other agricultural industry personnel, teachers, policy makers, and general citizens of the region. This report is a part of our ongoing conversations among all of these groups. We continue to be proud of what REACCH is accomplishing and remain deeply committed to producing results that will be useful to PNW agriculture.



REACCH conceptual framework and logic model.


REACCH
by the numbers 2011-2016
23.2 MILLION ACRES
3500 PRODUCERS
INLAND PACIFIC NORTHWEST
CLIMATE MODEL USED BY OVER
30
global research groups
279 PEOPLE PARTIALLY FUNDED BY REACCH @ UI OSU WSU
The REACCH study area is the most productive dryland wheat producing region in the world
77 TEACHERS TRAINED
CURRICULA SENT TO 6780 TEACHERS
4,234 views of farmer case studies
47 farmers
participating in multi-year survey
900 ag producers
participating in REACCH survey
25 MINI GRANTS TO INCREASE GROWER KNOWLEDGE
244 JOURNAL ARTICLES PUBLISHED


IDAHO, WASHINGTON AND OREGON
GROW 13.5% OF ALL U.S. WHEAT
2011 - 2015
wheat sales $6,500,000,000 | ~1 BILLION bushels produced | 85% exported
reacchpna.org
226,921 VISITS | 47,084 SESSIONS | 56.62% NEW USERS IN YEARS 5 AND 6
63 GRADUATE STUDENTS AND POST-DOCTORAL ASSOCIATES
75 UNDERGRADUATE RESEARCH SUMMER INTERNS
Flux towers collect 216,000 data points/hour measuring carbon and water vapor
A single 150-year climate simulation uses over 45 billion meteorological data points.
1290 data sets
571 conference presentations
338 presentations to stakeholders
285 fact sheets and blogs
115 videos on youtube.com
9,948 views
3908 views of aridcereals.org from 27 countries
2,633 views of 37 webinars
Infographic by Darci Deaton, compiled by Dianne Daley Laursen (diannedl@uidaho.edu)

Greenhouse Gas Emissions

Carbon, nitrogen, and water exchanges with the atmosphere

Contributed by Brian Lamb, blamb@wsu.edu, and
Erin Brooks, ebrooks@uidaho.edu

Issue: Agricultural cropping systems can be either net carbon sinks or sources, while cropland fertilization can lead to enhanced nitrous oxide (N_2O) emissions. Exchanges of the greenhouse gases carbon dioxide (CO_2) and N_2O over croplands can have large implications for climate change and agronomy practices.

Action taken: We deployed a network of five flux towers to yield 16 site years of continuously measured CO_2 and water fluxes, and we operated a hybrid chamber/flux tower system to measure N_2O emissions at two sites. The results were analyzed in terms of annual net carbon and water exchanges and N_2O emissions to establish a baseline for greenhouse gas budgets over wheat-cropping systems in the inland Northwest.

Results: Winter wheat crops exhibited an annual net carbon uptake, while spring crops were carbon neutral or exhibited a slight carbon loss. No-tillage sites resulted in lower carbon and water losses compared to conventional-tillage fields. Annual estimates of N_2O emissions (2 to 4 kilograms of nitrogen per hectare) exceeded the Intergovernmental Panel on Climate Change (IPCC) estimates for the region, which emphasizes the need for continued measurements to confirm this. Our results will help policy makers and growers understand how management practices affect the potential climate impacts of greenhouse gas uptake and loss from wheat-cropping systems in the inland Northwest.

Results published in:

Chi, J., S. Waldo, S. N. Pressley, P. O'Keeffe, W. L. Pan, E. Brooks, D. R. Huggins, C. O. Stöckle, and B. K. Lamb. 2016. Assessing carbon and water dynamics at two agricultural sites in the inland Pacific Northwest using the eddy covariance method Part II: Comparisons between no-till and conventional tillage cropping systems. *Agricultural and Forest Meteorology* 218–219: 37–49.

Waldo, S., J. Chi, S. N. Pressley, P. O'Keeffe, W. L. Pan, E. Brooks, D. R. Huggins, C. O. Stöckle, and B. K. Lamb. 2016. Assessing carbon and water dynamics at two agricultural sites in the inland Pacific Northwest using the eddy covariance method Part I: High- and low-rainfall cropping systems. *Agricultural and Forest Meteorology* 218–219: 25–36.

Eddy covariance tower to continuously measure the exchange of CO_2 over a wheat field.

Nitrogen loss from agricultural fields during high wind events was assessed using a series of profile samplers that trapped windblown dust; the profile samplers are located to the right of center in the photo.

Carbon and nitrogen losses due to erosion

Contributed by Brian Lamb, blamb@wsu.edu, and
Erin Brooks, ebrooks@uidaho.edu

Issue: There is a risk that future climate change will deplete organic carbon and organic nitrogen in the soil and therefore reduce overall soil fertility and crop productivity. In addition to atmospheric exchange with the crops, soil carbon and nitrogen are transported by wind and water, which degrades water and air quality. Maintaining soil organic carbon levels and minimizing the negative environmental effects of carbon transport require an understanding of how management can reduce carbon loss. However, few data sets are available that document carbon and nitrogen transport by wind and water in the Palouse region.

Action taken: Soil carbon and nitrogen transport by wind and water were measured at specific field sites across the region. In the western, arid region, where soil erosion is driven primarily by wind erosion, windblown dust samples were collected from multiple storm events and used to determine nitrogen loss rates. In the wetter, eastern region, soil carbon and nitrogen transport by water were measured from the micro-drainage scale to regional watershed scales. The effect of tillage management strategy on organic carbon transport was assessed at the field scale using both event-based water sampling and process-based computer modeling. The relative loss of dissolved organic carbon through subsurface tile drainage versus through surface runoff was also assessed at a long-term no-tillage site.

Results: Sediment and nitrogen loss associated with windblown dust for 13 high-wind events and eight site years showed that nitrogen loss from windblown dust ranged from 0.1 to 1.9 kilograms per hectare (kg/ha) across the 13 events, with annual losses that could exceed 5 kg/ha. The data indicate that the windblown dust was not enriched in nitrogen as compared with parent soil materials, which suggests that more-simplistic modeling efforts that ignore sorting processes to determine total nitrogen transport by wind are appropriate.

The water erosion data indicate that no-tillage practices greatly reduce soil organic carbon transport from 37 kilograms per hect-

Carbon export through surface runoff was monitored using parshall flumes and event-based water sampling. The image above was taken at the conventional tillage site.

are per year (kg/ha/yr) in conventional tillage to 6.6 kg/ha/yr in no-tillage. Interestingly, the majority of carbon loss from the no-tillage field (5.6 kg/ha/yr) was transported as dissolved organic carbon in the subsurface artificial tile drainage flow; we observed very little soil erosion. We observed a general decrease in total carbon export with increasing scale, ranging from 19 kg/ha/yr at the edge of the field to 13 kg/ha/yr from the Palouse River at Hooper, WA, suggesting that much of the carbon that erodes at the field scale deposits within the stream system.

The overall magnitude of soil carbon loss by wind and water at rates measured here is small relative to the overall soil carbon pool, estimated at 260,000 kg/ha in the top 1.5 meters of soil. However, process-based modeling indicates that without changes in tillage-management practices, soil carbon transport by erosion will likely increase by an order of magnitude by mid-century, which would negatively affect yields, especially for fields under conventional-tillage practices. Understanding the trends and effects of management on carbon export is an essential first step in the development of carbon budgets and full-scale cropping models capable of evaluating precision-based carbon-loss mitigation strategies.

Results published in:

Bellmore, R. A., J. A. Harrison, J. A. Needoba, E. Brooks, and C. K. Keller. 2015. Hydrologic control of dissolved organic matter concentration and quality in a semiarid artificially drained agricultural catchment. *Water Resources Research* 51: 8146–8164.

Sharratt, B., L. Graves, and S. Pressley. 2015. Nitrogen loss from windblown agricultural soils in the Columbia Plateau. *Aeolian Research* 18: 47-54.

Nitrous oxide emissions protocols for the Pacific Northwest

Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: Greenhouse gas emission-reduction programs (e.g., cap and trade) offer the possibility that voluntary farmer actions to reduce nitrous oxide (N_2O) emissions may be eligible for incentive payments through carbon-equivalent offsets. REACCH stakeholders have indicated significant interest in this strategy. Methodologies for quantifying emissions reductions of agricultural N_2O from nitrogen managment have been developed, but the available protocols have not been evaluated for the inland Pacific Northwest (PNW).

Action taken: We reviewed five N_2O-reduction protocols and performed a road test to quantify N_2O-emission offsets generated under inland PNW dryland wheat-based cropping systems.

Results: We concluded that the financial incentive from carbon offset credit alone is not likely to encourage any nitrogen management changes. Stacking of offset credit revenue, along with other incentive-based approaches, are likely required to realize policy-driven N_2O reductions in the region.

Results published in:

Brown, T., C. Lee, C. Kruger, and D. Huggins. Comparison of greenhouse gas offset quantification protocols for agricultural nitrogen management under Pacific Northwest dryland wheat. *Frontiers in Ecology and Evolution.* In review.

Vulnerability of wheat-based cropping systems to N_2O production

Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: Long-term agricultural management under conventional tillage or no-till may create different risks or vulnerabilities for the production of nitrous oxide (N_2O), a greenhouse gas, following rain events and/or nitrogen fertilizer applications.

Action taken: We assessed the short-term (hourly) production of N_2O following rain events and nitrogen fertilizer application in long-term management systems including conventional and no-till.

Results: We found that no-till systems produced less N_2O following both rainfall events and nitrogen fertilization than conventionally tilled systems and consequently are less vulnerable to these events.

Results published in:

Kostyanovsky, K. I., D. R. Huggins, C. O. Stöckle, J. G. Morrow, and W. L. Pan. N_2O and CO_2 production in wheat-based cropping systems – Effects of no-till. *Frontiers in Ecology and Evolution*. In review.

Automated static chambers monitor subsequent greenhouse gas emissions on micro-plots. Photo by Dave Huggins.

Biotic Factors in the Agroecosysytem

Earthworm survey can guide on-farm management for soil health

Contributed by Jodi Johnson-Maynard,
jmaynard@uidaho.edu

Issue: Earthworms are important indicators of soil health, a concept that is being widely promoted by the U.S. Department of Agriculture. Earthworms improve water retention in soils, which is important for dryland systems under predicted future climate scenarios. Greater knowledge of earthworm species and population densities is needed before farmers can manage for these important organisms and optimum soil health.

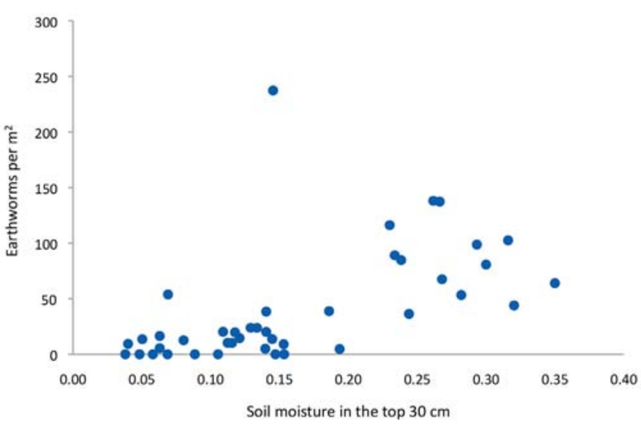
Action taken: We conducted the first comprehensive survey of earthworms in inland Pacific Northwest dryland agricultural systems.

Results: Earthworms are not found in areas where mean annual precipitation is below 330 millimeters. This is significant for predicting shifts in earthworm density under expected climate change and indicates climate change could have a detrimental effect on soil health in the future. Measured earthworm biomass values (94.3 grams per square meter) are generally high enough to benefit crop yields.

For the first time, we believe we can provide farmers with reasonable targets for earthworm management. We have a better understanding of which species will survive under expected climate change. This understanding will help to inform management decisions regarding earthworm inoculation, a practice of increased interest to growers.

Results published in:

Walsh, C. L., and J. L. Johnson-Maynard. 2016. Earthworm distribution and density across a climatic gradient within the Inland Pacific Northwest cereal production region. *Applied Soil Ecology* 104: 104–110.



Relationship between earthworm density and soil moisture across zones. Earthworm densities were generally higher at higher soil moisture levels, with much greater densities occurring in spring.

Metopolophium festucae cerealium, *the "wheat grass" aphid. Adults and nymphs are feeding on wheat. Photo by Brad Stokes.*

New aphid observed in the inland Pacific Northwest

Contributed by Sanford Eigenbrode,
sanforde@uidaho.edu

Issue: Injuries to wheat crops from insect pests vary with climatic factors and are in flux globally due to expansion of the pests' geographic ranges within and between continents. Long-term monitoring of pest complexes can detect these trends and inform timely responses.

Action taken: We conducted four annual surveys of the aphid fauna at more than 40 sites across the climatic zones of the inland Pacific Northwest (PNW). We also established a colony of a new aphid and tested it in the laboratory for its effects on wheat and its interactions with other aphids affecting cereal crops in the PNW.

Results: Throughout the four years of the survey, we detected large populations of *Metopolophium festucae cerealium*, an aphid species introduced from Europe and not previously reported to infest cereal crops in North America. In many locations, this species was the most abundant aphid detected. We documented the geospatial patterns of its occurrence and interpreted them in light of climatic drivers.

In the greenhouse, the aphid is more injurious per capita than most other aphids present in the region. While there is major concern that the new aphid may be a vector for *Barley yellow dwarf virus* (BYDV), a significant wheat pathogen worldwide, careful bioassays failed to detect BYDV transmission by the aphid, so it appears it is a problem only through it is direct feeding, which is much more manageable. Ongoing work is measuring the impacts of the aphid under field conditions to generate treatment guidelines for producers and studying the basis of its injury to the crop.

Results published in:

Davis, T. S., N. E. Foote, D. W. Crowder, N. A. Bosque-Pérez, and S. D. Eigenbrode. Plant water stress affects interactions between an invasive and a naturalized aphid species on wheat. *Environmental Entomology*. Submitted.

Davis, T. S., Y. Wu, and S. D. Eigenbrode. 2014. Host settling behavior, reproductive performance, and effects on plant growth of an exotic cereal aphid, *Metopolophium festucae* subsp. *cerealium* (Hemiptera: Aphididae). *Journal of Economic Entomology* 43: 682–688.

Foote, N. 2016. Effects of host plant water limitation on insect pestsof wheat in the Pacific Northwest. M.S. Thesis, University of Idaho.

Halbert, S. E., Y. Wu, and S. D. Eigenbrode. 2013. *Metopolophium festucae cerealium* (Hemiptera: Aphididae), a new addition to the aphid fauna of North America. *Insecta Mundi* 0301: 1–6.

Sadeghi, S. E., J. Bjur, L. Ingwell, L. Unger, N. A. Bosque-Pérez, and S. D. Eigenbrode. 2016. Interactions between *Metopolophium festucae cerealium* (Hemiptera: Aphididae) and *Barley yellow dwarf virus* (BYDV-PAV). *Journal of Insect Science* 16: 1–6.

Climate change and the abundance and timing of cereal aphid flights

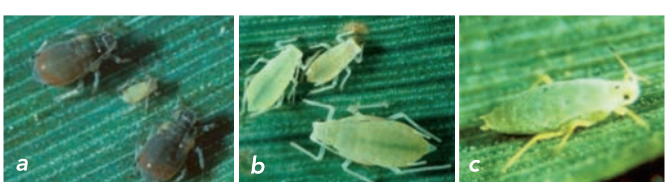
Contributed by Sanford Eigenbrode,
sanforde@uidaho.edu

Issue: Injury to wheat production systems from insect pests varies with climatic factors and is in flux globally due to expansion of the pests' geographic ranges within and between continents. Long-term monitoring of pest complexes can detect these trends and inform timely responses.

Action taken: We conducted a retrospective examination of a 17-year record of suction trap data from traps located in ID. These data allowed the construction of models that relate aphid flights to climatic factors over the 17-year period. The models will help to determine potential responses of aphids to future climatic trends.

Results: Three aphid species were most abundant in these suction trap records: *Rhopalosiphum padi* (bird cherry-oat aphid), *Metopolophium dirhodum* (rose grass aphid), and *Diuraphis noxia* (Russian wheat aphid). Over the 17-year record, each of these species responded differently to climate variability. Russian wheat aphid abundances were negatively correlated with increasing temperatures, while rose grass aphid abundances were positively correlated with increasing cumulative precipitation. In contrast, bird cherry-oat aphid was not responsive to the climate variables measured.

All three aphid species showed large-scale interannual fluctuations, showing that they are regulated by biological feedbacks that have yet to be determined. Thus, the contributions of density dependence (feedbacks) and climate to aphid population dynamics are species specific in spite of all three using wheat as a principal host. This outcome is consistent with other evidence that insect species respond differently to climate trends. The long-term trends in changes in abundance were relatively small compared to interannual cycling, so the implications for pest management do not seem to be great. The record does not include sequences of years as warm as anticipated in the region, so projections should be made with caution.

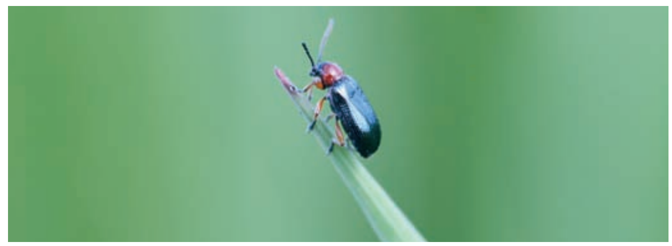


The four predominant aphids in historic suction trap records. (a) bird cherry-oat aphid, (b) rose grass aphid, (c) Russian wheat aphid, (d) English grain aphid.

Results published in:

Davis, T. S., J. Abatzoglou, N. A. Bosque-Pérez, S. E. Halbert, K. Pike, and S. D. Eigenbrode. 2014. Differing contributions of density dependence and climate to the population dynamics of three eruptive herbivores. *Ecological Entomology* 39: 566–577.

Merickel, J. W., B. Shafii, S. D. Eigenbrode, C. J. Williams, and W. J. Price. 2015. Modeling the occurrence of four cereal crop aphid species in Idaho. In: Reyes, P. E. (ed). *Applied Statistics in Agriculture*, Kansas State University, Manhattan, Kansas, pp. 1–38.



Adult Cereal leaf beetle on a wheat leaf. Photo by Nate Foote.

Cereal leaf beetle and future Pacific Northwest climates

Contributed by Sanford Eigenbrode,
sanforde@uidaho.edu

Issue: Injury to wheat production systems from insect pests varies with climatic factors and is in flux globally due to expansion of the pests' geographic ranges within and between continents. Projected changes in climate potentially influence pressure from certain pests.

Action taken: We used climate models to project changes in the suitability of Pacific Northwest climates for cereal leaf beetle (*Oulema melanopus*) under projected climate change to mid-century. The models also accounted for changes in impacts of *Terastichus julis*, a key parasitoid that currently suppresses beetle populations in the region. A process-based model of feeding by cereal leaf beetle as determined in laboratory experiments, coupled with the projected effects of changing climate on the growth of the wheat crop, was constructed to complement these projections.

Results: Warming trends will advance the phenology of cereal leaf beetle and increase the suitability of much of the region for its establishment and growth. The effects are not uniform across the region, with some parts of the range experiencing little or no change in suitability for the beetle (for example, much of Montana), while areas in the Columbia Basin consistently become better habitats for this pest.

In addition, data from a long-term study in Utah indicate that parasitism of cereal leaf beetle by its key natural enemy, *T. julis*,

continued next page

Biotic Factors in the Agroecosysytem

can be strongly suppressed by warm spring temperatures such as those projected to prevail over the region in the future. Together, these trends suggest that cereal leaf beetle could become a more problematic pest in the region than it is currently.

Finally, the process-based modeling indicates that changes in injury by the beetle will not be uniform across the region because differences in crop phenology and the beetle can influence its effect on the crop. These results suggest that increased injury by the beetle is more likely to occur in parts of the region with higher rainfall.

All of the models are based on certain assumptions and have limitations if those assumptions are not met, but the results suggest future vigilance regarding this pest.

Results published in:

Future manuscripts citations will be available on reacchpna.org.

Baseline distribution of soilborne pathogens of dryland cereals in the inland Pacific Northwest

Contributed by Tim Paulitz, paulitz@wsu.edu

Issue: Soilborne pathogens limit cereal yields in the dryland cropping systems of the inland Pacific Northwest (PNW). Both fungi and nematodes (microscopic, worm-like animals) attack cereal roots, damaging their ability to take up water and nutrients. Like all microbes, these pests are profoundly affected by soil moisture and temperature. How are these pathogens distributed among the climatic zones of the inland PNW? More importantly, how will they be distributed in future climate scenarios, and what impact will they have?

Action taken: To answer this question, we first needed to establish a baseline: where are the pathogens now, and how does their distribution correlate with temperature and precipitation records of the last 30 years? We developed DNA techniques to measure the populations of these pathogens directly from soil samples. We conducted extensive spatial surveys across eastern WA for three species of *Rhizoctonia* (cause of bare patch and root rot), two species of *Fusarium* (cause of crown rot), and *Pratylenchus* (root-lesion nematodes). We used various statistical methods to compare their distributions with spatial models of 30-year temperature and precipitation averages, scaled down to 4 kilometers.

Rhizoctonia *bare patch of wheat.*

Results: We found that *Rhizoctonia solani* AG-8, the cause of bare patch, was somewhat correlated with sandier soils and lower precipitation, concentrated in the wheat–fallow areas of Ritzville-Connell. *Fusarium pseudograminearum* was found more frequently in warmer areas with less precipitation (wheat–fallow zones) compared to *Fusarium culmorum*, which was found more frequently in cooler, higher-precipitation areas of annually cropped zones. The nematode *Pratylenchus* was more common in annually cropped zones than in wheat–fallow because it requires a living host to reproduce.

Both of the fungal pathogens can grow on dead roots and crop residue and can survive in the absence of the host; hence, they are well adapted to cropping systems with fallow years or rotation crops such as legumes. These baseline studies provide a basis for future climatic modeling of these soilborne root pathogens.

Results published in:

Kandel, S. L., R. W. Smiley, K. Garland-Campbell, A. A. Elling, J. Abatzoglou, D. Huggins, R. Rupp, and T. C. Paulitz. 2013. Relationship between climatic factors and distribution of *Pratylenchus* spp. in the dryland wheat production areas of Eastern Washington. *Plant Disease* 97: 1448–1456.

Kandel, S. L., R. W. Smiley, K. Garland-Campbell, A. A. Elling, D. Huggins, and T. C. Paulitz. Spatial distribution of root lesion nematodes (*Pratylenchus* spp.) in a long-term no-till cropping system and their relationship with crop rotation, soil, and landscape properties. *Plant Disease*. Submitted.

Okubara, P. A., K. L. Schroeder, J. T. Abatzoglou, and T. C. Paulitz. 2014. Agroecological factors correlated to soil DNA concentrations of *Rhizoctonia* in dryland wheat production zones of Washington state, USA. *Phytopathology* 104: 683–691

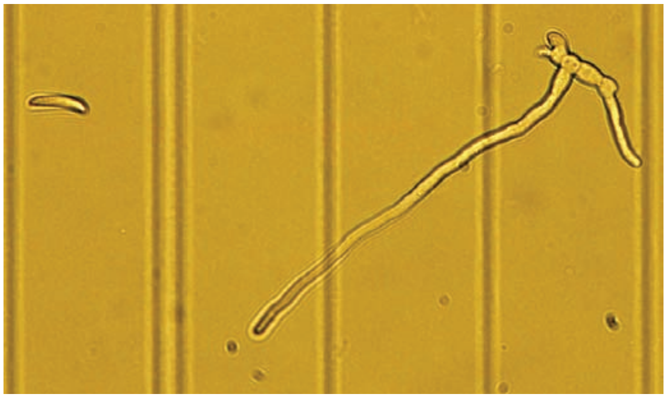
Poole, G. J., R. W. Smiley, C. Walker, D. Huggins, R. Rupp, J. Abatzoglou, K. Garland-Campbell, and T. C. Paulitz. 2013. Effect of climate on the distribution of *Fusarium* species causing crown rot of wheat in the Pacific Northwest of the US. *Phytopathology* 103: 1130–1140.

How do temperature and moisture affect fungal pathogens of wheat?

Contributed by Tim Paulitz, paulitz@wsu.edu

Issue: To predict how soilborne fungal pathogens will be distributed under future climate scenarios in the inland Pacific Northwest, we need to know how they respond to temperature and moisture (water potential). However, nothing was known at a basic level of how the growth of two important pathogens, *Fusarium* and *Rhizoctonia*, was affected by these environmental conditions.

Action taken: With the development of new water potential measurement technologies by Decagon, we were able to experimentally vary the availability of water and grow *Fusarium* and *Rhizoctonia* under a combination of different water and temperature levels. We measured the growth of the fungi, the ability of their spores to germinate, and their ability to colonize straw pieces, which they can use as a food source in the soil.



A spore of Fusarium culmorum *germinating at -9 megapascals (MPa) (-90 bars). The original spore has four cells; two of the cells have germinated to form a hypha, which can attack the plant root. For comparison, 1 bar is roughly 1 atmosphere or 15 pounds per square inch, and at this water level, water is being held extremely tightly, making it very hard for most organisms to get the water and grow.*

Results: Both *Fusarium pseudograminearum* and *Fusarium culmorum* (causes of crown rot) can grow under extremely dry conditions, down to -7 to -9 megapascals (MPa). This is extremely dry; plants permanently wilt at -1.5 MPa, and most fungi and bacteria cannot grow at this water level. On the other hand, species of *Rhizoctonia* (cause of bare patch and root rot) prefer wetter conditions and are restricted beyond -1 MPa. The optimum temperature for *F. culmorum* and *R. solani* is 20° to 25°C (68° to 77°F), whereas *F. pseudograminearum* and *R. oryzae* have optimums of 25° to 30°C (77° to 86°F).

The fungi that cause Fusarium crown rot are adapted to growing under the dry soil conditions present during the summer growing season, whereas the *Rhizoctonia* species are more adapted to growing in wetter conditions in spring. This information will be useful for making distribution models of these pathogens under future climate-change scenarios.

Results published in:

Aujla, I. S., and T. C. Paulitz. 2015. Effect of temperature and water potential on the hyphal growth rate of *Fusarium* and *Rhizoctonia* pathogens of wheat. *Phytopathology* 105: S4.9.

Aujla, I., and C. T. Paulitz. 2016. Standardizing water potential of salt-amended growth media at different temperatures for microbial studies. *Phytopathology* 106: S4.30.

Microbial communities in no-till wheat systems

Contributed by Tim Paulitz, paulitz@wsu.edu

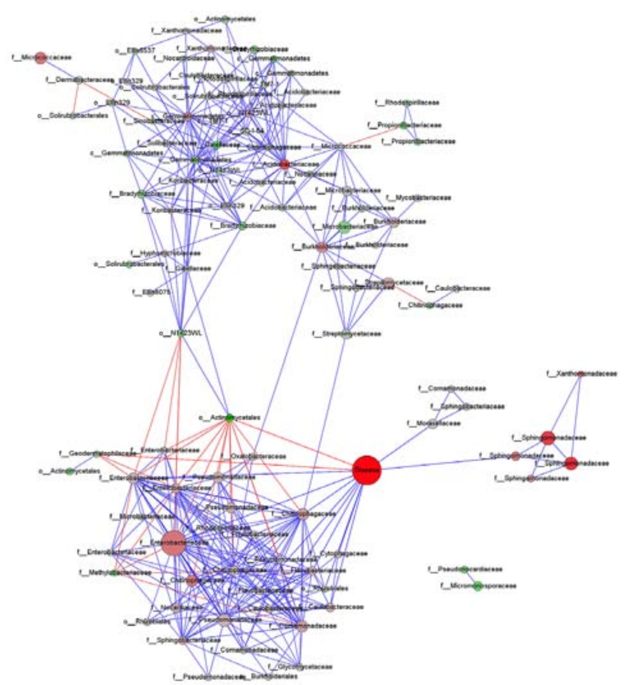
Issue: Besides fungal pathogens, thousands of other species of fungi and bacteria are present in soil. Many of these play a beneficial role in helping plants take up nutrients and defend against disease. Fungi are especially important in the carbon cycle as decomposers of crop residue.

Little is known about these microbial communities, but within the last decade tools have been developed that can produce tens of thousands of DNA sequences from a single soil sample, so we can identify thousands of microbe species. For the first time, we can look at the entire microbial community without having to culture microbes in the lab. Since no-till agriculture will be an important tool to mitigate climate change in the future (more carbon storage in the soil, less fossil fuel use, less erosion), we wanted to see if long-term, no-till cultivation would shift microbial populations, especially beneficial ones.

Action taken: We sampled soils at two locations over two years, one near Pullman, WA, and one near Genesee, ID. At each location we sampled plots that had been in long-term no-till (12 and 30 years) and adjacent plots that were conventionally tilled. Using next-generation sequencing tools, we generated millions of DNA sequences of bacteria and fungi, which we identified and analyzed for abundance and diversity. We also used network analysis to see how these groups were linked together and to further describe the community.

Results: A few groups of bacteria were influenced by tillage, but most were not. The bacteria around the root were a distinct community compared to what was in the soil, and they were influenced even less by tillage. The plant was the primary determinant of this community, which feeds on carbon exuded from the root.

On the other hand, fungal communities were much more influenced by tillage, and we identified distinct groups that were more dominant in no-till or conventional tillage plots. These differences may reflect the source of carbon. In conventional tillage, the residues are tilled into the soil, whereas in no-till, much of the carbon remains above ground, with root tissue being the main source of carbon in the soil. The fungal communities may play a



Network analysis of bacteria in relation to Rhizoctonia bare patches, showing some groups are associated with diseased plants and some groups with healthy plants.

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Biotic Factors in the Agroecosysytem

role in suppressing *Rhizoctonia*, a fungal pathogen that seems to disappear in long-term no-till systems.

Results published in:

Yin, C., S. H. Hulbert, K. L. Schroeder, O. Mavrodi, D. Mavrodi, A. Dhingra, W. F. Schillinger, and T. C. Paulitz. 2013. The role of bacterial communities in the natural suppression of Rhizoctonia bare patch of wheat (*Triticum aestivum* L.) *Applied and Environmental Microbiology* 79: 7428–7438.

Yin, C., K. Schroeder, N. Mueth, A. Prescott, A. Dhingra, S. Hulbert, and T. C. Paulitz. Bacterial communities on wheat grown under long-term conventional tillage and no-till in the Pacific Northwest of the US. *Phytobiome*: Submitted.

Downy brome genetics and its projected development under climate change

Contributed by Nevin Lawrence, nlawrence2@unl.edu

Issue: Within the small-grain production region of the Pacific Northwest (PNW), downy brome is a ubiquitous and competitive weed. Changing climate may impact the timing of crop-weed competition and the window for when weed-control inputs are effective.

Action taken: We employed a genotype-by-sequencing approach to call molecular markers, generate population genetic statistics, and classify downy brome accessions into genetically similar clusters. We also transplanted accessions into three common garden field sites to document and model the timing of their development. We modeled the timing of development stages against cumulative growing degree days to develop herbicide application thresholds to aid in control of downy brome within small-grain fields.

We later initiated greenhouse experiments to characterize the responses of early-, intermediate-, and late-to-flower downy brome accessions to various vernalization treatments and quantify the expression of *Brachypodium distachyon* gene vernalization 1 (*BdVRN1*). Downscaled climate modeling was paired with global climate change models to project downy brome development thresholds under future climate scenarios based upon the results of our field and greenhouse experiments.

Variation in downy brome maturity across the PNW small-grain production region.

Results: We identified six genetic clusters of downy brome across the PNW using 384 single-nucleotide polymorphisms and the discriminant analysis of principal components clustering approach. The estimate for mature seed production varied from May 18 to June 20 depending upon the location of the common garden. Earlier production of mature seed was observed following more-severe winters compared to mild winters, implying a role for vernalization in regulating the timing of development. Downy brome flowering in response to vernalization treatments was linked to the expression of *BdVRN1*, implying the molecular controls of flowering in downy brome are similar to the controls in other temperate grass species.

Under all future climate scenarios, downy brome development is anticipated to advance 16 to 34 days across the small-grain production region of the PNW. Downy brome is likely to remain a severe pest well into the next century, and the changing climate may complicate control efforts. The earlier development of downy brome will require earlier control inputs, which may conflict with earlier rainfall projected under future-climate scenarios.

Results published in:

Lawrence, N. C. 2015. Adaption to climate change and small grain production systems by *Bromus tectorum*. Ph.D. Dissertation. Washington State University.

Climatic factors affect wireworm biology and management

Contributed by David Crowder, dcrowder@wsu.edu

Issue: Wireworms are among the most damaging insect pests of cereal crops, and the population dynamics of wireworms may be strongly affected by climate. However, no extensive research detailing links between wireworms and climate had been conducted in the inland Pacific Northwest (PNW); this has inhibited management of these pests.

Action taken: We conducted three years of experiments to determine how climatic factors affect the population dynamics and management of different wireworm species.

Results: In the dryland region of the inland PNW, two species of wireworms are dominant, the sugarbeet wireworm, *Limonius californicus*, and the western field wireworm, *Limonius infuscatus*. Although these two species can have different impacts on cereal crop production, growers have managed them as a single complex. Our research shows, however, that the sugarbeet wireworm is tolerant of a much broader array of environmental conditions than the western field wireworm.

The western field wireworm has a relatively short period of activity early in the season as soil temperatures rise, but its feeding activity declines rapidly after April when high soil temperatures become limiting. Our research also shows that prophylactic treatments of seed-applied neonicotinoid pesticides are the most effective strategy for managing this species; the treatments are highly effective soon after planting.

Wireworms feed on the roots and seeds of cereal crops.

In contrast, the sugarbeet wireworm continues to feed throughout the summer regardless of soil temperatures, and it is not effectively managed by seed-applied insecticides. Our research suggests that crop rotations may be more effective for control of this species.

Our results show that understanding how climate affects different wireworm species can be used to design more targeted Integrated Pest Management (IPM) programs. Ongoing research is exploring novel control tactics for wireworms, such as biological control, that will reduce the use of prophylactic insecticide treatments.

Results published in:

Esser A. D., I. Milosavljevic, and D. W. Crowder. 2015. Effects of neonicotinoids and crop rotation for managing wireworms in wheat crops. *Journal of Economic Entomology* 108: 1786–1794.

Milosavljevic I., A. D. Esser, N. A. Bosque-Pérez, and D. W. Crowder. 2016. The identity of belowground herbivores, not herbivore diversity, mediates impacts on plant productivity. *Scientific Reports* 6: 39629

Milosavljevic I., A. D. Esser, and D. W. Crowder. 2016. Effects of environmental and agronomic factors on soil-dwelling pest communities in cereal crops. *Agriculture, Ecosystems and Environment* 225: 192–198.

Milosavljevic I., A. D. Esser, and D. W. Crowder. 2016 Seasonal population dynamics of wireworms in wheat crops in the Pacific Northwestern United States. *Journal of Pest Science*. DOI: 10.1007/s10340-016-0750-y.

Drought stress alters a host-vector-pathogen interaction

Contributed by Sanford Eigenbrode,
sanforde@uidaho.edu

Issue: Both short-term and long-term water stress may become more frequent under a changing climate. *Barley yellow dwarf virus* affects wheat in some parts of the Pacific Northwest, but it was unknown how the pathogen interacts with these types of drought stress.

Action taken: In a greenhouse study, we tested whether drought stress alters host-virus interactions of *Barley yellow dwarf virus* and wheat. We explored whether the interaction between water supply and pathogen infection affects host plant growth and seed set and what the consequences are when plants undergo drought and then recover.

Results: We found significant interactions between host infection status and water quantity. In plants that received adequate water, uninfected plants set more seed, but in plants that received low amounts of water, infection status had no effect on the amount of seed set. In fact, in plants that were placed under water stress and then allowed to recover, infected plants surpassed uninfected plants in growth, seed set, seed germination frequency, and seed mass.

Barley yellow dwarf virus and drought are both injurious to wheat, but their effects are not additive. Instead, infected wheat tolerates water stress better than uninfected wheat. Our findings suggest that yield projections under the dual stresses of drought and virus infection could be modified upward, influencing decisions about whether harvest is justified when both stresses occur simultaneously.

Results published in:

Davis, T. S., N. A. Bosque-Pérez, N. E. Foote, T. Magney, and S. D. Eigenbrode. 2015. Environmentally dependent host-pathogen and vector-pathogen interactions in the *Barley yellow dwarf virus* pathosystem. *Journal of Applied Ecology* 52:1392–1401.

Davis, T. S., N. A. Bosque-Pérez, I. Popova, and S. D. Eigenbrode. 2015. Evidence for additive effects of virus infection and water availability on phytohormone induction in a staple crop. *Frontiers in Ecology and Evolution* 3:114

Barley yellow dwarf virus-*infected wheat in southern Idaho.*

Increasing Efficiencies

Improving cropping system flexibility in the inland Pacific Northwest with win-win scenarios

Contributed by Bill Pan, wlpan@wsu.edu

Issue: While it is recognized that water drives wheat nitrogen use efficiency (yield per nitrogen supply) in the inland Pacific Northwest (PNW), we had only a rudimentary understanding of how water influences the plant and soil components of single-crop and rotational nitrogen use efficiencies across diverse rotations. Evaluating key management variables such as cover cropping, tillage, and crop rotation will help identify best management practices that improve water and nitrogen use during increasing summer temperatures and moisture stress during climate change. Our goal is to identify win-win scenarios that meet producers' short-term goals and develop long-term adaptation and mitigation strategies.

Action taken: We coordinated eight crop-rotation trials across low-, intermediate-, and high-rainfall zones in the inland PNW to gain a better understanding of water- and nitrogen use efficiencies across crop sequences adapted to the soil and climate conditions of each location. We established standardized methods for soil and plant sampling and analysis to assess crop sequential water- and nitrogen use efficiencies.

Results: Our research illustrates the importance of nitrogen fertilizer carryover and subsequent uptake by spring wheat and spring pea and by winter wheat in three-year rotations. Furthermore, we developed methodology for assessing water- and nitrogen use efficiencies across whole crop sequences, as opposed to the more typical single-crop assessment, and tested it on these and other regional rotational data. The basic methodology is being applied across REACCH study sites to evaluate relative nitrogen- and water-use efficiencies of conventional and alternative rotations across the region. Variables being compared include tillage and residue management, nitrogen fertilizer management, crop rotation, and recycling organic amendments.

No-till winter canola planted into tall winter wheat stubble. Photo by Lauren Port.

Results published in:

Maaz, T., and W. L. Pan. Residual fertilizer and crop sequence impact rotational N use efficiency. *Agronomy Journal*. In revision.

Maaz, T. M., L. Port, W. L. Pan, W. Schillinger, I. Madsen, H. Collins, and A. Esser. 2015. Rotational nitrogen and water use efficiencies in intensified and diversified cropping systems across the precipitation gradient of Eastern WA. In: *Climate Change and Cereal Production in Semi-Arid Regions of the World*. REACCH International Conference Abstracts. Minneapolis, MN.

Pan, W., D. Huggins, F. Young, B. Schillinger, A. Esser, S. Machado, J. Johnson-Maynard, T. Maaz, I. Madsen, L. Port, H. Collins, V. McCracken, K. Painter, K. Borrelli, E. Brooks, C. Stöckle, and S. Eigenbrode. Win-win cropping system strategies for farmers and climate change. *Frontiers of Ecology and Environment.* In preparation.

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

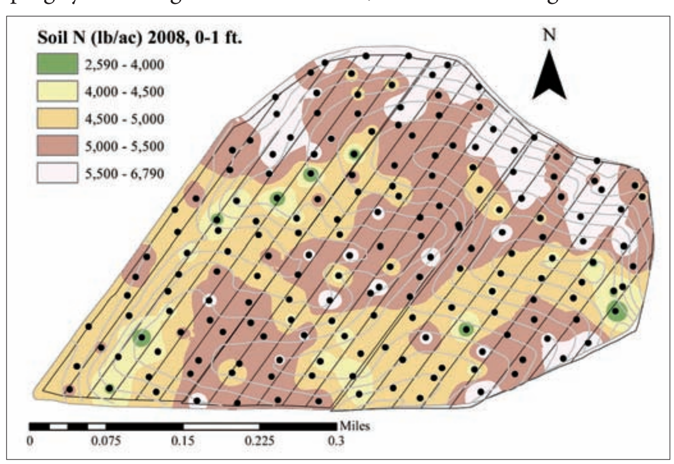
Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: Assessing nitrogen use efficiency on a single-crop basis can underestimate the actual efficiency that can occur over the course of several crop rotations. This actual longer-term nitrogen use efficiency has rarely been quantified.

Action taken: We assessed nitrogen use efficiency over the course of 10 years at the Cook Agronomy Farm at Pullman, WA, by monitoring initial soil nitrogen levels, amounts of nitrogen applied, removal of crop nitrogen at harvest, and final soil nitrogen levels.

Results: We found that the conversion from conventional tillage to no-tillage increased soil profile nitrogen by 35 pounds per acre annually. This indicates that soil organic matter was increasing over this time period and that additional nitrogen inputs were needed as nitrogen is an important component of soil organic matter.

The nitrogen use efficiency calculated for the longer-term cropping system ranged from 65 to 85%, about two times greater



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

than what is typical for a single crop. This occurs because applied fertilizer nitrogen cycles through soil organic matter where it is stored and can be used by subsequent crops.

Quantifying nitrogen use efficiency based on longer-term cropping system evaluations is an improved approach over single-year assessments; however, long time periods are required, and errors associated with the measurements make accurate quantification problematic.

Results published in:

Unger, R., D. E. Huggins. 2015. Cropping system nitrogen use efficiency after 10 years of no-tillage. In: Borrelli et al. (eds.), *Regional Approaches to Climate Change for Pacific Northwest Agriculture: Climate Science Northwest Farmers Can Use*. pp. 62-63.

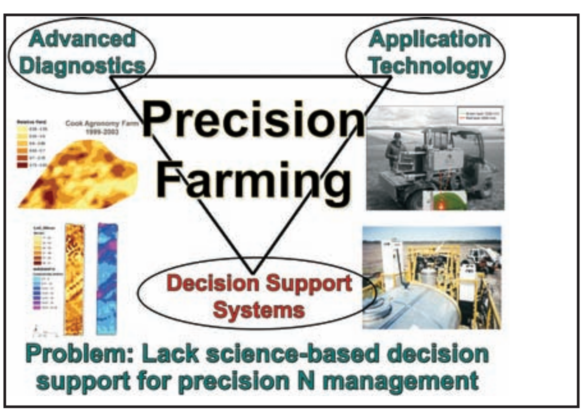
Precision nitrogen and seeding rate management: Developing science-based practices

Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: The current practice of precision agriculture lacks science-based decision support tools to enable the application of available technology and crop diagnostic capabilities.

Action taken: We conducted field-scale nitrogen application and seeding rate experiments to evaluate wheat performance (yield, protein, nitrogen use efficiency) under precision agricultural practices versus business as usual.

Results: We discovered that growers often divide fields into too many nitrogen management zones with the result that precision nitrogen management may not meet performance expectations. We developed methodology based on long-term, site-specific relative yields within a field that assesses the probability of obtaining a given yield outcome and consequently the field location's suitability for applying precision technologies. We discovered that low-producing portions of fields are prime locations for substantially reducing nitrogen and seeding rates as compared to current recommendations. These results enable farmers to reduce variable costs associated with fertilizer and seed as well as to improve efficiencies of nitrogen use.



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

Results published in:

Brown, T. T. 2015. Variable rate nitrogen and seeding to improve nitrogen use efficiency. Ph.D. Dissertation. Washington State University Department of Crop and Soil Sciences.

Taylor, S. E. 2016. Precision nitrogen management: Evaluation and creating management zones using winter wheat performance. M.S. Thesis. Washington State University Department of Crop and Soil Sciences.

Taylor. S. E., D. R. Huggins, and D. J. Brown. Evaluation of site-specific nitrogen application in dryland winter wheat. *Precision Agriculture*. In review.

Cropping System Diversification

Winter pea adaptation into wheat cropping systems

Contributed by Bill Pan, wlpan@wsu.edu, and Bill Schillinger, schillw@wsu.edu

Issue: The wheat monoculture farming predominant in the inland Pacific Northwest has led to environmental, economic, and soil-quality problems. Crop rotation using legumes reduces fertilizer nitrogen use, diversifies the biology of crop rotations, and allows farmers to control troublesome winter annual grass weeds. Some crop diversification has been implemented using cool-season legumes in the high-rainfall zone of the region, but options are more limited in the lower-rainfall zones.

Action taken: We conducted studies of spring peas in high- and intermediate-rainfall zones in Pullman, WA, and Davenport, WA, to determine the extent of biological nitrogen fixation. In addition, we introduced winter peas into a long-term crop rotation study in the low-rainfall zone at Ritzville, WA, where the winter wheat–summer fallow rotation has dominated for 135 years.

Results: Spring peas in Pullman biologically fixed most of their plant N, while fixation was not as dominant at Davenport, where the peas were more reliant on residual soil nitrogen supplies. This suggests that pea inoculation is critical where fields have had no previous history of legume production.

At Ritzville, winter peas have produced high yields, fixed nitrogen, and shown good overwinter hardiness, likely because the shoot meristem remains below ground, as in wheat, and benefits from soil insulation against freezing winter temperatures. Winter peas offer a viable crop rotation option for this traditional wheat–fallow region. In the past five years, farm planting of winter peas has gone from zero to more than 10,000 acres. This trend is expected to grow as farmers gain experience and confidence in winter pea production.

Winter pea (right) and winter wheat (left) in early May at the test site in Ritzville, WA. Photo by Bill Schillinger.

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Cropping System Diversification

Results published in:

Abi-Ghanem, R., T. Maaz, W. Schillinger, H. Kaur, D. Huggins, and B. Pan. 2014. Intensifying grain legume production in dryland cropping systems. In: Borrelli et al. (eds.), *Regional Approaches to Climate Change for Pacific Northwest Agriculture: Climate Science Northwest Farmers Can Use*. pp. 18–19.

Schillinger, W. F., K. D. Braunwart, and H. R. Nelson. 2016. Winter pea: Promising new crop for Washington's winter wheat-fallow region. American Society of Agronomy annual meeting, 6-9 Nov., Phoenix, AZ. ASA, CSSA, SSSA Abstracts.

Schillinger, W., R. Jirava, J. Jacobsen, and S. Schofstoll. 2015. Winter pea crop rotation study at Ritzville, WA. In: Borrelli et al. (eds.), *Regional Approaches to Climate Change for Pacific Northwest Agriculture: Climate Science Northwest Farmers Can Use*. pp. 34–35.

Canola adaptation and integration for reducing nitrogen footprint in the inland Pacific Northwest

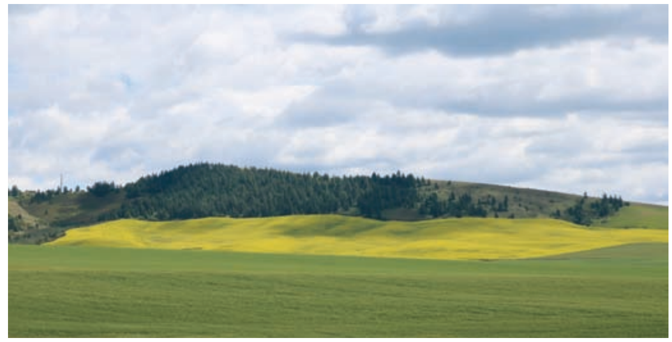
Contributed by Bill Pan, wlpan@wsu.edu

Issue: Dryland farming in the inland Pacific Northwest (PNW) is largely monocultural. Producers grow wheat, with some limited integration of cool-season legumes in the high-rainfall zone only. Canola has been identified as a prime candidate for diversifying and improving the sustainability of wheat-based cropping systems in the region, and it would also mitigate climate change by providing biodiesel feedstock in place of fossil fuels and improving nitrogen cycling and nitrogen use efficiency (yield per nitrogen supply). However, little information was available on spring canola's nitrogen fertilization requirements or on the nitrogen requirements of rotations including canola.

Also, while it is recognized that water drives wheat nitrogen use efficiency (yield per nitrogen supply) in the region, we had only a rudimentary understanding of how water influences the plant and soil components of single crop and rotational nitrogen use efficiency. In addition, predictive methods and nitrogen management recommendations needed to be updated to reflect new crops and rotations as the climate changes.

Action taken: We conducted a seven-year field experiment (2007 to 2014) in intermediate- and high-precipitation zones of the inland PNW to define spring canola and rotational nitrogen requirements as influenced by water availability. We also conducted controlled rhizosphere experiments to illustrate how the differences in root and shoot morphology between wheat and canola necessitate a change in nitrogen placement, form, and timing strategy when adapting wheat-based farming technology to canola production.

Results: We developed new nitrogen recommendations for inland PNW canola production. Our study illustrated the importance of nitrogen fertilizer carryover and subsequent uptake by spring wheat and spring pea and by winter wheat in three-year rotations. In addition, our study revealed potential damage to canola seedlings from conventional wheat planting and fertilization equipment and fertilizer placement strategies.



Canola on a Palouse hillside adjacent to field sections of wheat. Photo by K. Sowers.

Furthermore, we developed methodology for assessing rotational water- and nitrogen-use efficiencies across whole crop sequences, as opposed to the more typical single crop assessment, and tested it on these and other regional rotational data. The basic methodology is being applied across REACCH study sites to evaluate relative rotation nitrogen and water-use efficiencies of conventional and alternative rotations across the REACCH region.

Our results form the basis for several upcoming extension grower guides on canola nitrogen management, leading to improved cropping system nitrogen use efficiency and a reduced nitrogen footprint for the inland PNW.

Canola production has increased in WA from 7,000 acres in 2008 to 31,000 to 54,000 acres in the period 2014 to 2016, with similar increases throughout the inland PNW. We sustained the activities of a stakeholder network that includes research and extension faculty, students, seed and chemical suppliers, financial institutions, government agencies, farmers, and experts in grain storage, processing, and marketing. This network has assured oilseed-processing industry investment in the region, represented by oilseed processing plants established at Warden and Odessa, WA, which ensures local markets and the overall sustainability of the WA oilseed movement and value-added industries. Viterra, an international marketer and handler of grains and oilseeds, encouraged by the efforts and progress of this oilseed network, has a supply and marketing agreement with the Warden facility and has begun to pursue an aggressive business plan to crush over 1,100 metric tons of seed per day to be processed into biodiesel and various grades of food-grade canola oil from locally grown canola. In parallel, plans are being made to convert the Odessa plant into a camelina processing facility for food and industrial oil production.

Results published in:

Beard, T., K. Sowers, and W. Pan. 2016. Physiology matters: Adjusting wheat-based management strategies for oilseed production. Publication FS 244E. Washington State University Extension, Pullman.

Long, D., F. Young, W. Schillinger, C. Reardon, J. Williams, B. Allen, W. Pan, and D. Wysocki. 2016. Ongoing development of dryland oilseed product ion systems in northwestern region of the United States. Bionenergy Research OnLine DOI 10.1007/s12155-016-9719-1.

Maaz, T., W. L. Pan, and A. H. Hammac. 2016. Influence of soil nitrogen and water supply on canola nitrogen use efficiency of canola. *Agronomy Journal* 108: 2099–2109.

Maaz, T. M., J. D. Wulfhorst, V. McCracken, H. Kaur, I. Roth, D. Huggins, A. Esser, J. Kirkegaard, and W. Pan. Economic, policy, and social challenges of introducing oilseed and pulse crops into dryland wheat rotations. *Agriculture, Ecosystems and Environment*. In revision.

Pan, W. L., T. M. Maaz, W. A. Hammac, V. A. McCracken, and R.T. Koenig. 2016. Mitscherlich-modeled, semi-arid canola nitrogen requirements influenced by soil N and water. *Agronomy Journal* 108: 884–894.

Pan, W. L., I. J. Madsen, L. Graves, T. Sistrunk, and R. Bolton. 2016. Ammonia/ammonium toxicity of root meristems and root hairs as influenced by inorganic and organic fertilizer sources and placement. *Agronomy Journal* 108: 2485–2492.

Pan, W. L., F. L. Young, S. C. Hulbert, D. R. Huggins, and T. M. Maaz. 2016. Canola integration into semi-arid wheat cropping systems of the inland Pacific Northwestern USA. *Crop and Pasture Science* 67(4): 253–265.

Winter triticale and canola show promise in low-rainfall zone

Contributed by Lauren Young Port, leyoung@wsu.edu

Issue: Growers in the low-rainfall production zone of the inland Pacific Northwest have few crop-rotation options that are both economically and environmentally sustainable.

Action taken: We evaluated no-till winter triticale and winter canola as alternative crops for the low-rainfall zone at Ralston, WA.

Results: Winter triticale yielded 126 to 180% of winter wheat. This yield advantage is necessary, as triticale garners a lower price than wheat. Based on the winter triticale yields in our study, it is an economically viable alternative to winter wheat. A high-residue no-till system focused on maintaining winter triticale straw to protect the soil surface resulted in better maintenance of seed-zone soil moisture when compared to reduced-till fallow.

Winter canola seedling emerging from under a thick layer of winter triticale residue.

Winter canola is seeded at a shallower depth than winter cereal crops, meaning that soil moisture must be closer to the soil surface to support germination of the canola seed. At Ralston, increased seed-zone soil moisture in the high-residue no-till system led to greater establishment of winter canola when compared to the drier seed zone in reduced-till fallow.

Results published in:

Port, Lauren E., F. L. Young, and W. L. Pan. Managing high-residue no-till fallow in the low-rainfall zone of the Pacific Northwest. Intended for submission to *Crop, Forage & Turfgrass Management*.

Crop diversification at WSU Wilke Farm

Contributed by Aaron Esser, aarons@wsu.edu

Issue: The low- and intermediate-rainfall zones in the dryland cropping region of eastern WA often rely on a tillage-based, summer-fallow system to produce winter wheat. Yet reducing fallow and improving crop diversity are important to reduce erosion and improve long-term soil health.

Action taken: The Washington State University Wilke Research and Extension Fam is a 320-acre direct-seeded facility located in the intermediate-rainfall zone. The farm has been divided into eight large plots (22 to 67 acres each). One plot is in a continuous crop rotation, three plots are in a 3-year rotation (no-till fallow–winter wheat–spring cereal), and four plots are in a 4-year rotation (no-till fallow–winter wheat–broadleaf crop–spring cereal). We collected agronomic and economic data each year comparing the performance of the three rotations.

Results: There has been no difference in returns over production costs between the 3-year and 4-year rotations, and both of these rotations have outperformed the continuous crop rotation. Our findings have helped farmers stretch their rotations and reduce the overall amount of summer fallow and especially tillage-based summer fallow. Since the inception of this project, an estimated 25 farmers within a 20-mile radius of the farm have purchased direct-seed drills. These farms represent significant acreage under a no-till or direct-seed farming system.

Results published in:

Esser, A. D., and D. P. Appel. 2015. WSU Wilke Research and Extension Farm production and economic performance 2013. Technical Bulletin TB02. Washington State University Extension.

Esser, A. D., and D. P. Appel. 2015. WSU Wilke Research and Extension Farm production and economic performance 2014. Technical Bulletin TB03. Washington State University Extension.

Esser, A. D., and D. P. Appel. 2016. WSU Wilke Research and Extension Farm production and economic performance 2015. Technical Bulletin TB20. Washington State University Extension.

Esser, A. D., and D. P. Appel. WSU Wilke Research and Extension Farm production and economic performance 2016. Washington State University Extension. Technical Bulletin. Submitted.

Technological Advances

Stripper header crop residues reduce wind speeds at the soil surface

Contributed by Lauren Young Port, leyoung@wsu.edu

Issue: Intensive tillage in the low-rainfall production zone of eastern WA results in erosion-prone soils.

Action taken: Long-term research at Ralston, WA, has evaluated novel cropping systems and residue management techniques to reduce soil erosion. We introduced winter triticale, which produces more biomass than winter wheat, as a rotational crop. We harvested it with a stripper header, which resulted in tall crop residues that we then managed with chemical fallow.

Results: During the chemical fallow period, tall residues remained in place and protected the soil from wind, which also allowed for maintenance of seed-zone soil moisture. Average wind speeds at the soil surface in tall triticale residue were one-third of the wind speeds measured over reduced-tillage fallow. These reduced wind speeds can help reduce wind erosion and dangerous dust storm events.

Growers have embraced the stripper header, as it allows them to harvest faster while maintaining crop residues. Since the initiation of this phase of research, stripper headers have been adopted on thousands of acres in Washington's low-rainfall production zones. Many of the growers who have recently purchased stripper headers are in the process of transitioning to no-till production, which will continue to benefit the sustainability of our cropping systems.

Barley stem after stripper header harvest. Kernels have been stripped from the head, leaving the rachis intact and hardly damaging the flag leaf.

Results published in:

Port, L. E., F. L. Young, and W. L. Pan. Managing high-residue no-till fallow in the low-rainfall zone of the Pacific Northwest. *Crop, Forage & Turfgrass Management*. In preparation.

Performance criteria for evaluating site-specific nitrogen management

Contributed by Dave Huggins, dhuggins@wsu.edu

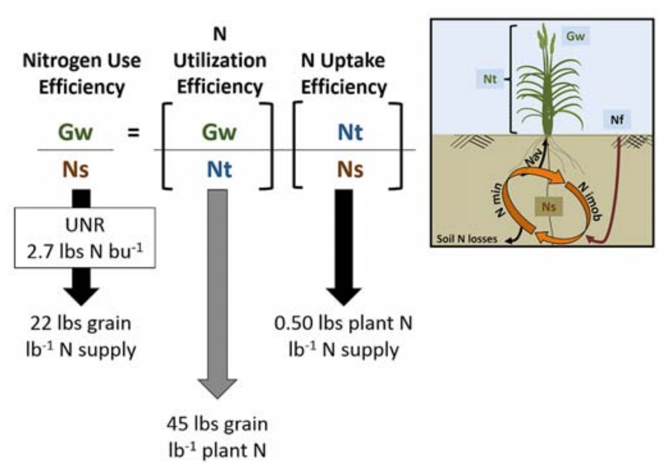
Issue: Precision nitrogen management often emphasizes the development of prescription maps that are the basis for variable-rate nitrogen applications. However, we lack performance criteria to assess if precision applications achieve crop-performance goals.

Action taken: We developed performance criteria including yield, grain protein, and nitrogen use efficiency to classify the within-field performance of wheat, including the results of precision nitrogen management strategies.

Results: We found that performance outcomes that resulted from precision nitrogen applications based on prescription maps varied considerably within management zones. This indicates that nitrogen management prescriptions could be further improved within precision management zones currently used for winter wheat. The performance classes we developed are a useful tool to assess crop outcomes with respect to farming goals and provide a framework for expanding the assessment of other performance goals such as water-use efficiency, revenue, greenhouse gas production, and soil erosion.

Results published in:

Brown, T. T., D. Huggins, J. R. Reganold, C. K. Keller, and C. E. Kruger. Developing nitrogen use efficiency performance criteria to evaluate site-specific management of winter wheat. *Precision Agriculture*. In review.



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

Decision Support Tools

AgBizClimate™ online decision tool measures farm-level impacts of climate change

Contributed by Clark Seavert,
clark.seavert@oregonstate.edu

Issue: Most agricultural producers have a limited understanding of climate change and of how it may impact their specific farm and ranch enterprises. This results in a lack of understanding of the importance of developing adaptation strategies to reduce economic and financial risks.

Action: We developed a farm-level climate change decision support tool, *AgBizClimate*™, to assess the potential impacts of a changing climate on the net returns of current management and current agricultural systems. We worked with regional producers to identify 14 climate variables that could impact agricultural production practices.

AgBizClimate™ links with a suite of economic and financial modules known collectively as *AgBiz Logic*™ and provides essential economic, financial, and climatic information that producers and policy makers need to assess adaptation-management and policy options. Growers use their own enterprise budgets from *AgBiz Logic*™ to measure the impacts of climate change on net returns based on changing yields, product quality, and production inputs.

The climate variables in *AgBizClimate*™ include number of nights below freezing per year, accumulated chilling hours, seasonal minimum temperature, seasonal maximum temperature, accumulated growing degree days, number of warm nights per year, number of heat wave events per year, number of cold snap events per year, diurnal temperature range, growing season length per year, accumulated water year precipitation, maximum number of consecutive wet days per year, maximum number of consecutive dry days per year, and number of very heavy precipitation days.

Results: *AgBizClimate*™ broadens producers' understanding of how a variety of regional climate characteristics will impact their production costs and the quantity and quality of their agricultural products. It can be applied to wheat and cereal production in the Pacific Northwest as well as to apples and other specialty crops. Once growers see how climate may change for their particular county, they begin to realize that tools are available that can assist them in measuring the financial impacts, and, using other *AgBiz Logic*™ modules, they begin to develop long-term adaptation strategies.

To learn more about *AgBizClimate*™, visit http://www.agbizlogic.com.

AgBiz Logic™ helps growers make long-term financial decisions

Contributed by Clark Seavert,
clark.seavert@oregonstate.edu

Issue: A majority of agricultural producers do not have adequate accounting data to conduct an accurate and meaningful capital investment analysis for long-term decisions.

AgBizClimate™ can evaluate adaptation strategies to reduce the impacts of climate change, such as equipment costs for no-till drills. Photo by Kurt Schroeder.

Action taken: We developed *AgBiz Logic*™, an online decision tool that enables growers to assess the economic, financial, and sustainability implications of alternative management practices as future scenarios. This tool links with a suite of economic, finance, and environmental modules known collectively as *AgBiz Logic*™ and provides essential information that producers and policy makers need to assess technology, adaptation strategies, and policy options.

The foundation of *AgBiz Logic*™ is return and cost budgets for specific enterprises on a per-unit basis and by region. However, as many as 85 percent of agricultural producers do not have the accounting data to construct these budgets. *AgBiz Logic*™ allows growers to take their existing federal income tax records, accounting information, and university and industry budgets to develop general and detailed budgets for their own farm and ranch enterprises. In addition, it allows growers to develop plans, a sequence of budgets that describes a situation over a period of time, and to develop scenarios, a set of plans to be compared to each other, that serve as the basis for the economic, financial, and environmental modules.

Growers can collect data from their federal income tax Schedule F forms or easily "drag and drop" accounting data from Excel spreadsheets and .csv files into *AgBiz Logic*™ gold standard categories. The data are then allocated to business enterprises—crops, livestock, nursery, etc.—and then allocated within each enterprise; for example, in crops the data might be allocated to cereal grains, row crops, vine crops, etc. This provides the information required to begin developing enterprise budgets on a per-unit basis by field, block, head, or herd.

Results: Growers have used *AgBiz Logic*™ successfully on its initial release. They understand and are pleased with the ease of collecting their financial data and of allocating it to business enterprises and budgets.

To learn more about *AgBiz Logic*™, visit http://www.agbizlogic.com.

Decision Support Tools

WSU Post Harvest Nitrogen Efficiency Calculator

Contributed by Aaron Esser, aarons@wsu.edu

Issue: Wheat farmers traditionally make fertilization decisions based on their previous application history and, secondarily, on soil sample data. Few wheat farmers have known how to predict nitrogen fertilizer needs based on their previous crop production and nitrogen use efficiency.

Action taken: We developed a decision tool for nitrogen fertilization using Washington State University (WSU) Extension Bulletin EB1987E. The WSU Post Harvest Nitrogen Efficiency Calculator allows wheat farmers to improve their nitrogen application program based on nitrogen use efficiency data.

Results: In combination with multiple extension outreach presentations, the calculator has improved growers' understanding of wheat fertilization based on the quantity of nutrients applied prior to harvest and the quantity of nutrients removed from the field at harvest. Grower surveys determined that between 25% and 71% of growers are utilizing nitrogen use efficiency to make nitrogen fertilization decisions on their farms. This finding has been reaffirmed through verbal conversations with local grain elevators where farmers have specifically requested grain protein be reported on their settlement sheets.

Results published in:

http://wheattools.wsu.edu/Applications/Fertilizer%20Use%20Calculator/PostHarvestEfficiency

REACCH produces web-based climate and weather tools

Contributed by Katherine Hegewisch, khegewisch@uidaho.edu

Issue: The REACCH project produced over 20 terabytes (TB) of climate data, including historical gridded meteorological observations, seasonal climate forecasts, and future climate projections covering the contiguous US at a 4-kilometer (2.5 mile) resolution. This data has been largely inaccessible to researchers and stakeholders due to its sheer size, unfamiliar format, and lack of tools to analyze the data.

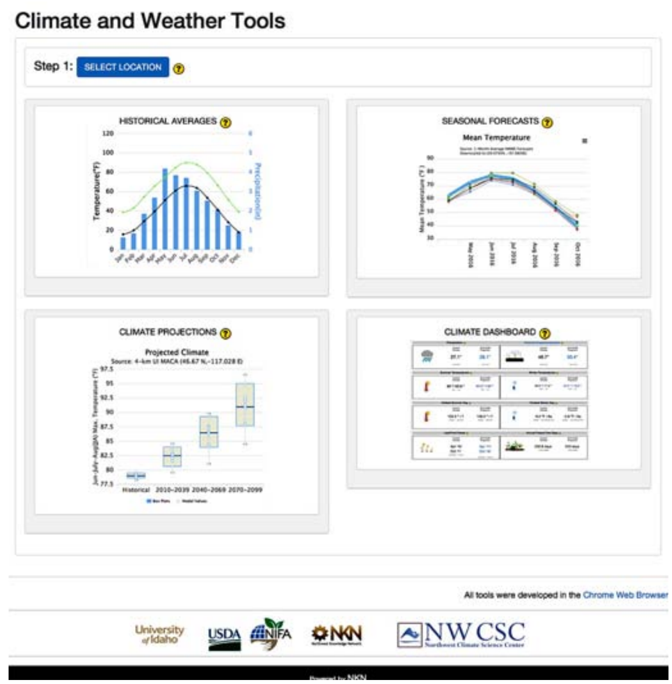
Action taken: We developed a set of climate and weather web tools that utilize REACCH climate datasets to both create interactive graphics and acquire datasets in accessible formats. The climate and weather tools allow users to extract and visualize climate data for any location in the contiguous US. We developed tools to examine summaries of historical and future climate as well as seasonal forecasts for the next seven months.

Results: The climate and weather tools allow visualization of the REACCH datasets over the contiguous US and are currently accessible through Decision Support Tools at the REACCH website. These tools are being integrated into two other sets of web tools—the Northwest Climate Toolbox (http://climatetoolbox.org) and the Integrated Scenarios website (http://climate.nkn.uidaho.edu/IntegratedScenarios/)—which are being used by U.S. Geological Survey climate science centers, U.S. Department of Agriculture climate hubs, the U.S. Forest Service, and many individual researchers to better understand climate variability, change, and impacts.

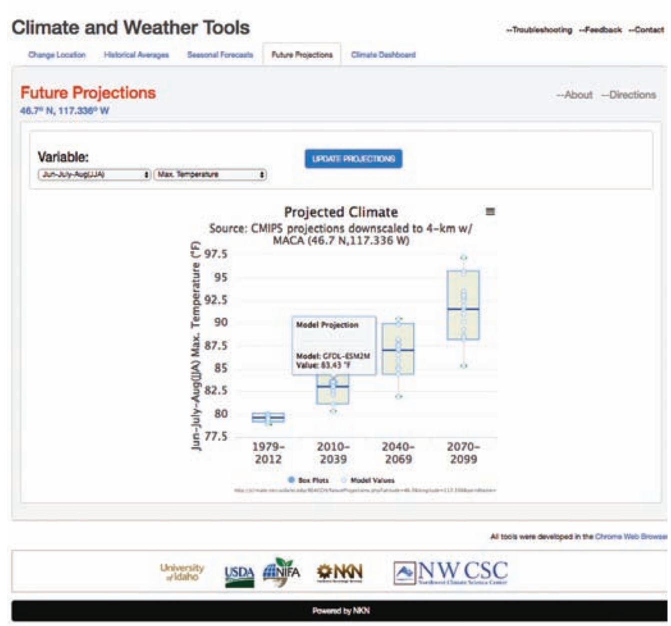
Results published in:

http://climate.nkn.uidaho.edu/REACCH/climateTools.php

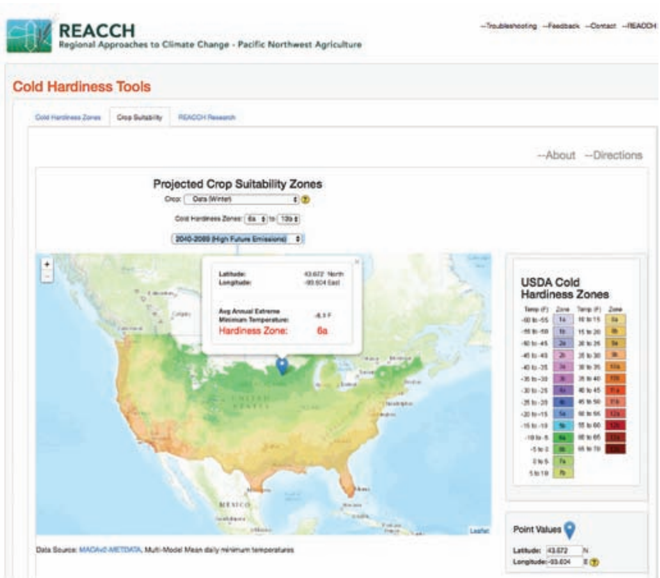
https://www.reacchpna.org/tools



Landing webpage for REACCH climate and weather tools showing the four tools related to past observations, seasonal forecasts, and future climate projections.



The Future Projections tool in action showing future projections of summer maximum temperatures over the early, mid, and late 21st century for a location near Moscow, ID.



The Crop Suitability tool in action showing mid-21st century projections of regions suitable for growing winter oats (according to cold hardiness zone) and highlighting the future hardiness zone for a location in the Midwest.

Crop and pest management web tools help inform grower decisions

Contributed by Katherine Hegewisch, khegewisch@uidaho.edu

Issue: The REACCH project produced research on agricultural science and management. Such research advances are often inaccessible to decision makers, which creates a barrier between scientific knowledge and decision-making.

Action taken: We developed a set of crop and pest management web tools (http://climate.nkn.uidaho.edu/REACCH/decisionTools.php) that utilize REACCH research and climate datasets to help inform grower decisions. For example, we developed a web-based interface for examining thermal suitability for crop selection under both current and future climates over the contiguous US. We developed tools to monitor crop phenology and associated implications for pest and weed management. We also created a set of webpages that provide information on identification and life cycles of pests and weeds, including economic threshold calculators for pesticide spraying and seed treatment.

Results: The decision support tools are currently accessible through Decision Support Tools at the REACCH website. We conducted a series of focus groups with stakeholders to improve content and accessibilty of our tools. The focus groups validated interest in our tools among producers. These tools are also being integrated into another set of web tools called the Northwest Climate Toolbox (http://climatetoolbox.org).

Results published in:

https://www.reacchpna.org/tools

Understanding economic and environmental tradeoffs with climate change

Contributed by Laurie Houston, Laurie.Houston@oregonstate.edu

Issue: Climate change and increased climate variability will affect agriculture in many ways that will have both farm-level impacts and regional impacts. Farmers and growers need to be cognizant of the risks and opportunities that future weather patterns may bring to yields and profitability as well as to the possible environmental outcomes associated with changes in their management regimes.

A tool or set of tools that can link farm-level decisions to regional outcomes is needed to address the economic and environmental tradeoffs associated with changes in climatic conditions and to inform future policy. Such tools will improve decision-making under climate change by increasing agricultural productivity and incomes, adapting and building resilience to climate change, and helping to enhance food security under a changing climate.

Action taken: We are linking a farm-scale decision support tool called AgBiz Logic® (https://www.agbizlogic.com/) with a region-scale tool called TOA-MD (http://agsci.oregonstate.edu/tradeoffs). *AgBiz Logic®* collects farm-level enterprise data and could provide high-quality, timely data at relatively low cost. A data system that links farm management software to a confidential database could provide near-real-time data on management decisions and do so for a statistically representative "panel" of farm decision makers over time. The level of detailed management data utilized by *AgBiz Logic®* would provide the needed level of detail for using a tool such as TOA-MD, which can examine a variety of economic, social, and environmental tradeoffs on a regional scale. TOA-MD models the whole farm system (crops, livestock, aquaculture, non-farm income) and simulates mean and threshold economic indicators (per-capita income, income-based poverty) as well as other quantifiable economic, environmental, and social outcomes associated with the systems.

Results: We have contributed a chapter to a forthcoming Climate-Smart Agriculture publication by the Food and Agriculture Organization of the United Nations. Our chapter describes a case study that uses the dryland wheat-producing area of the US Pacific Northwest to illustrate how decision-support tools can be designed to address the farm-scale tradeoffs associated with changes in climatic conditions and to allow both farmers and policy makers to evaluate climate-smart options to optimize farm-level net returns and regional environmental outcomes.

Results published in:

Capalbo, S. M., C. Seavert, J. M. Antle, J. Way. and L. L. Houston. Understanding tradeoffs in the context of farm-scale and regional impacts: An application of decision-support tools for assessing climate smart agriculture. Food and Agriculture Organization of the United Nations. Forthcoming.

Grower Knowledge

Producer profiles demonstrate benefits of advanced farming practices

Contributed by Patrick Mazza, cascadia2012@gmail.com

Issue: Many producers in the inland Northwest cereal-growing region have implemented climate-friendly farming practices that have proven beneficial for their agronomics and returns. Farm producers give highest credibility to their peers, and so demonstrating successful use by peers of advanced farming practices is a powerful tool for disseminating them. Many of the producers' stories are not well known, however, creating a need for accessible materials that demonstrate success and agricultural benefits.

Action taken: We identified five producers who use exemplary climate-friendly practices, secured their cooperation, and made visits to their farms to conduct in-depth interviews. Among practices featured were:

- No-till in a low-rainfall regime, making possible crop diversification and cover cropping

John Aeschliman has been restoring soil life with no-till practices since the 1970s. The ground now is filled with earthworms. Here, Aeschliman points out how worms aerate and fertilize the soil. Photo by Alex Garland.

- Long-term no-till that began in the 1970s, with benefits including restoration of soil life, moisture retention that enables high yields and the ability to grow crops such as dryland corn, and direct seeding into lands going out of the Conservation Reserve Program (CRP) without tillage or burning
- Premium marketing, based on no-till soil benefits, to bring increased returns and support no-till growth
- Economical use of precision agriculture on a small farm
- Use of unmanned aerial vehicles to provide real-time information for crop management and precision agriculture

The five producer profiles we wrote tell the personal stories of the farmers, how they adopted climate-friendly practices, and the benefits they have realized. The relative brevity of the articles enhances their impact and readability, as do the magazine-feature writing style and layout and high-quality photo illustrations.

Results: Producer profiles provide extension tools for dissemination among farmers, telling the stories of successful farmers in an accessible way. Employing the power and credibility of farmer-to-farmer communication, these tools build confidence among farmers that climate-friendly practices are viable and profitable. This makes it more likely producers will implement such practices in their own operations.

Results published in:

https://www.reacchpna.org/social-dynamics

Public perceptions of climate change risk

Contributed by J. D. Wulfhorst, jd@uidaho.edu

Issue: The general public is a major stakeholder in climate change adaptation. Until REACCH, the Pacific Northwest (PNW) had no baseline information about public perceptions of climate change risks within the region, especially risks related to agriculture and food security.

Action taken: We implemented the first representative survey of the general public to assess baseline perceptions about climate change in the three-state region. In general, the survey addressed the need within the PNW to identify and capture public input on the cause and effects of climate change.

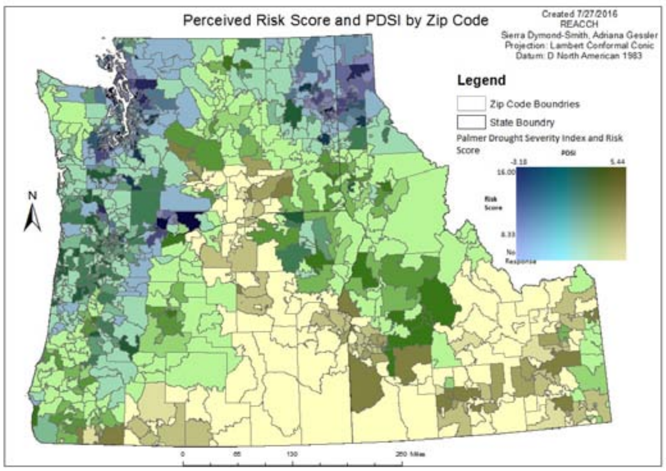
Results: In 2016, capitalizing on this survey effort, a team of undergraduate interns conducted an integrated analysis by combining the social perception data with key biophysical variables such as elevation, average temperature, distance from coast, and drought tolerance. These measures provide needed information to address USDA's mission, "helping improve the economy and quality of life in all of rural America."

The results indicate the general public is about twice as likely to understand climate change as a human-caused phenomenon than as a natural phenomenon. Those who perceive the issues are human caused also tend to show higher levels of concern about the effects of climate change. Women in the region tend to perceive a greater level of risk from climate change than do men. Additionally, 90% of respondents indicated at least some agreement that climate change poses risks to agriculture globally. The baseline results suggest that many people in the Pacific Northwest understand the importance of agriculture and the need for agriculture to adapt to a changing climate.

Results published in:

Dymond-Smith, S., A. Gessler, and J. D. Wulfhorst. 2016. Perceived risk of climate change in the Pacific Northwest: A Geographic Look at Public Perceptions. Presented at the 7th Annual Northwest Climate Conference, November 14-16, Stevenson, WA.

Bernacchi, L., J. D. Wulfhorst, L. McNamee, and M. Reyna. 2014. Pioneering public perception of climate change and agriculture in the Pacific Northwest. Presented at the 5th Annual Northwest Climate Conference, September 9-10, Seattle, WA.



Level of socially perceived risk from climate change among the general public by drought severity zones and by zip code jurisdictions in the Pacific Northwest.

Mapping social perception of risk in agroecological classifications

Contributed by J. D. Wulfhorst, jd@uidaho.edu

Issue: Although previous research has increased our understanding of cereal producer adaptation behaviors within the Pacific Northwest, the results have not measured climate change contexts or provided geo-reference points to spatially map survey data.

Action taken: We conducted the first cross-sectional and comparative survey to measure cereal producers' perceptions of climate change. We then created analytical structures to visualize the results within agroecological classification systems.

Results: Preliminary analyses focused on integrating producer survey data and other REACCH project components and on finalizing an agroecological classification for each producer (Figure 1). While figure 1 does illustrate respondent dispersion across the three agroecological classifications used in the project (delineated as percent fallow: annual cropping [0–10%], intermediate [11–40%, and crop-fallow [> 40%]), it also shows how

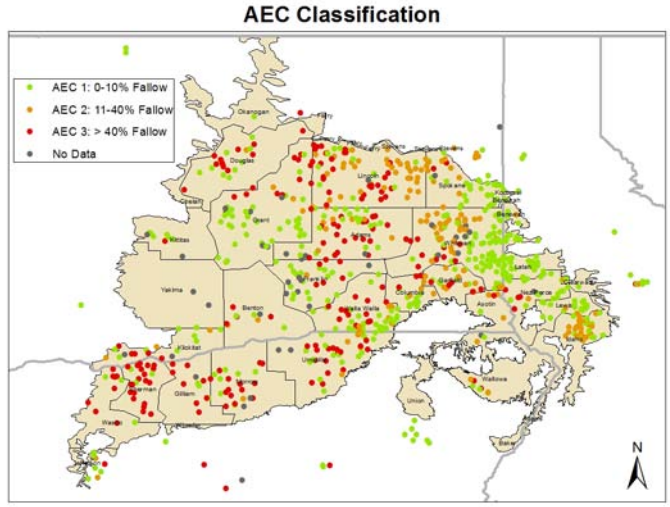


Figure 1: Producer respondents as classified within an agroecological system.

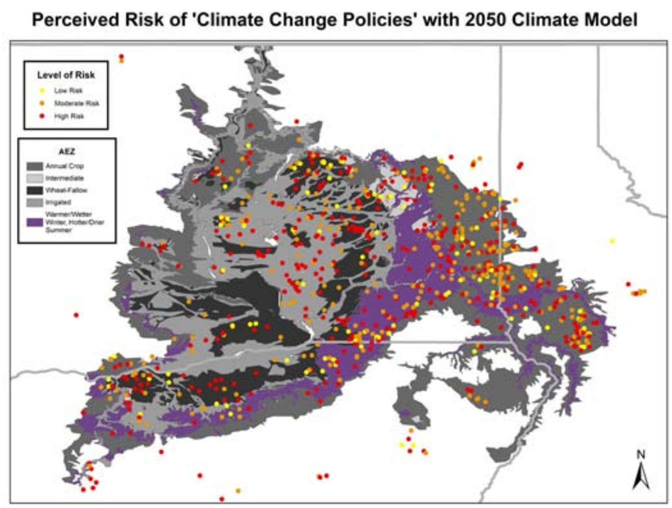


Figure 2: Producers' level of perceived risk to their operation from climate change policies depicted within a modeled characterization of agroecological zones in the year 2050, which was presented and described in the survey.

the classification system is dynamic in that the geography of the classes will likely shift over time.

When coupled with other metrics within the survey, the mapped analyses display the intersections of the agroecological classifications and attitudes of the respondents (Figure 2). This map highlights the level of perceived risk (low, medium, high) among producers about how climate change policies may affect their operations. It maps the responses within a futuristic model of agroecological zones predicted for the region. Results highlight that producers in the intermediate- and fallow-zone subpopulations on average tend to perceive higher risk to their operations.

Results published in:

Wulfhorst, J. D., J. Gray, L. McNamee, and I. Roth. Applying classification systems to wheat producers' perceptions of climate change risk in the Inland Pacific Northwest. *Agriculture, Ecosystems & Environment.* In preparation.

Grower Knowledge

Temporal-scale social analyses with Pacific Northwest grain producers

Contributed by J. D. Wulfhorst, jd@uidaho.edu

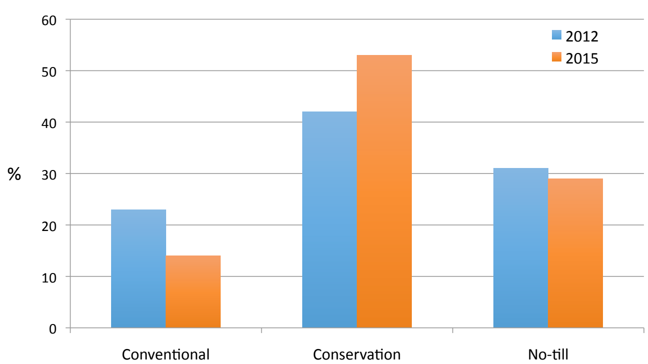
Issue: Given its variable precipitation, erodible soils, and over 35 years of concentrated research on farm conservation practices, the Pacific Northwest (PNW) has a unique record of agricultural production and rural sociological research. Although not planned as a longitudinal experiment, the region lends itself to the kind of case study rarely reported in rural sociology and risk management literatures—a long-term agricultural community analysis to understand adaptation trends over time, including to climate change.

Action taken: We continued social analyses of producer perspectives in the inland PNW, adding the capacity to analyze producer views of climate change and providing baseline data on how producers carry out operations in the region.

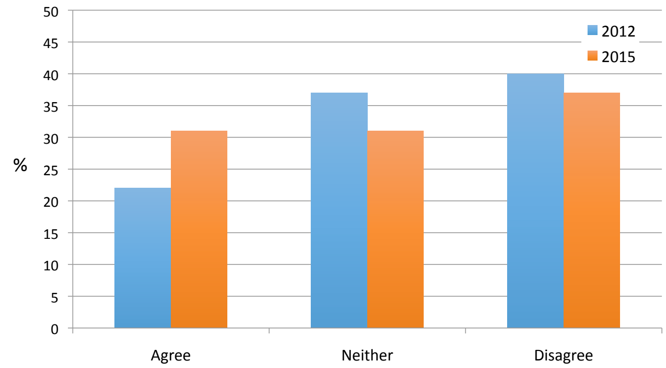
Results: In 2012 and 2015, we conducted the latest region-wide surveys with wheat producers via baseline and follow-up surveys. One of the core questions asked of respondents was the level of tillage and types of practices they use in the operation. As shown in the accompanying figure, there continues to be a trend over time from conventional toward conservation-oriented tillage. The 2015 results indicate a slight decrease in no-till practitioners, but the result is not statistically significant. More telling, the overall trend toward the conservation end of the scale between 2012 and 2015 is a substantive increase and indicates that while many producers continue to deny human-caused climate change, many continue to adapt their operations toward best-management practices based in conservation.

Results published in:

https://www.reacchpna.org/social-dynamics



Tillage practices of inland Northwest wheat producers in 2012 and 2015 (n = 900 with a response rate of 46% in 2012; n = 462 with a response rate of 43% in 2015).



Change in producer perspectives between 2012 and 2015 about whether they will have to make serious changes in their farm operations to adjust to climate change.

Documenting farmer perspectives on climate change

Contributed by J. D. Wulfhorst, jd@uidaho.edu

Issue: Prior to REACCH, and despite predictions for significant and rapid change in the Pacific Northwest (PNW) climate, there was comparatively little understanding of the social science aspects of a changing climate in the region. Yet knowledge about basic elements such as people's beliefs about climate change is needed for identifying adaptation and mitigation scenarios in public policy.

Action taken: We conducted a baseline assessment of community and producer perspectives on climate. We also accomplished a longitudinal comparison among producers that is unique among agricultural regions. We measured producer perceptions about whether a changing climate would affect their operations.

Results: In 2012, we found that while 80% of producers agreed they have observed weather patterns changing in their lifetime, a much smaller proportion (39%) agreed that the average global temperature is increasing. Even fewer (21%) agreed that human activities are the primary cause of climate change. These results suggest that producers differ from the general public as a whole, which increasingly perceives human activities as the cause of climate change.

In our longitudinal comparison, we documented a substantial increase between 2012 and 2015 in the percentage of producers who perceive that they will have to make changes to their operations due to climate change.

Results published in:

Wulfhorst, J. D., L. McNamee, and I. Roth. Climate change beliefs among wheat producers and effects to operational decision-making. *Frontiers in Ecology and Evolution*. Submitted.

Network of extension educators and agricultural professionals developed

Contributed by Georgine Yorgey, yorgey@wsu.edu

Issue: To best support the future productivity and resilience of Pacific Northwest farming, we need to expand the network of extension educators and agricultural professionals capable of communicating with regional stakeholders about agriculture and climate change.

Action taken: We have reached 500 to 750 individuals each year through live presentations on issues related to climate change and agriculture. We also hosted the "Agriculture in a Changing Climate" workshop and are distilling its outcomes into a set of priorities for research and extension in the region. We have expanded our online content on reacchpna.org and established the Agriculture Climate Network (agclimate.net), which provides agricultural educators and professionals with ongoing regional resources and the opportunity to stay engaged and up-to-date on issues relating to climate change and agriculture.

Results: The Agriculture Climate Network (agclimate.net) was established and developed as a resource for agricultural extension educators and agricultural professionals. The website was visited 2,181 times in 2016 and now has 80 newsletter subscribers, 169 Twitter followers, and 93 Facebook followers. After the "Agriculture in a Changing Climate" workshop, 100% of those who completed an evaluation said they had gained knowledge relating to climate change and agriculture. In addition, 71% were planning behavioral changes based on what they learned and experienced at the conference, while an additional 19% were considering behavioral changes.

The Agriculture Climate Network is online at agclimate.net.

Results published in:

Yorgey, G. G., C. E. Kruger, B. R. Saari, S. A. Hall, E. Whitefield, N. Embertson, V. P. Jones, K. Rajagopalan, E. Allen, G. Roesch-McNally, B. Van Horne, J. Abatzoglou, H. Collins, L. Houston, C. Seavert, and T. Ewing. 2016. Agriculture in a changing climate: Research and extension priorities in the Pacific Northwest. White Paper. Center for Sustaining Agriculture and Natural Resources, Washington State University, Mt. Vernon, WA.

Groups report back after facilitated breakout sessions during the Agriculture in a Changing Climate Conference in Kennewick, WA in March 2016.

Attendees at a field day event in north-central Washington in May 2014.

Wide-ranging extension efforts help prepare growers for climate change

Contributed by Georgine Yorgey, yorgey@wsu.edu

Issue: To best support the future productivity and resilience of Pacific Northwest (PNW) farming, farmers need improved management knowledge relevant to mitigating and adapting to climate change.

Action taken: We produced and supported field days, conference talks, webinars, blog articles, factsheets, and other educational materials that provide management-specific knowledge relevant to mitigating and adapting to climate change in dryland farming systems in the PNW.

Results: Grower surveys across the region in summer 2016 indicated that 86% of respondents had gained knowledge relevant to mitigation (e.g., soil carbon management), while 79% had gained new knowledge relating to adaptation (e.g., managing pests, weeds, and diseases). Meanwhile, 87% had made changes to improve management of soil carbon, and 88% had made changes to improve management of pests, weeds, and diseases.

Results published in:

https://www.reacchpna.org/social-dynamics

Multimedia case studies share farmers' innovative practices

Contributed by Georgine Yorgey, yorgey@wsu.edu

Issue: New strategies are needed—and need to be shared with growers—to maintain productive and sustainable farming operations across the landscape of the Pacific Northwest as the climate changes.

Action taken: Through 11 multimedia case studies, we shared the innovative practices that forward-thinking farmers in the region are using, practices that have the potential to ameliorate climate change impacts. We are also preparing a book to be published by Washington State University Extension that summarizes research advances through the lens of the management decisions that farmers make.

continued next page

Grower Knowledge

Results: We completed 11 case study videos and wrote three case studies; others are in progress. By the end of 2016, our videos had been viewed over 6,000 times. They have supported numerous conferences across the region, including the Pacific Northwest Direct Seed Association's, and "Irrigated High Residue Farming" workshops. Our written case studies had been read more than 70 times. Publication of our book *Advances in Dryland Farming in the Inland Pacific Northwest* is scheduled for April 2017.

Our case studies are available at https://www.reacchpna.org/case_studies

Results published in:

Yorgey, G. G., K. Borrelli, A. McGuire, and K. Painter. Strip tillage and livestock integration: Eric Williamson (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication. Washington State University Extension, Pullman. In preparation.

Yorgey, G. G., K. Borrelli, and K. Painter. Enhancing cropping diversity: Steve and Nate Riggers (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication. Washington State University, Pullman. In preparation.

Yorgey, G. G., K. Borrelli, and K. Painter. Grazed cover cropping: Drew Leitch (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication, Washington State University Extension, Pullman. In preparation.

Yorgey, G. G., K. Borrelli, K. M. Painter, and H. Davis. Conservation tillage in a winter wheat – fallow system: Ron Jirava (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication. Washington State University Extension, Pullman. In review.

Yorgey, G. G., K. Borrelli, K. M. Painter, and H. Davis. Stripper header and direct seeding, Ron and Andy Juris (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication. Washington State University Extension, Pullman. In press.

Yorgey, G. G., S. I. Kantor, C. E. Kruger, K. M. Painter, H. Davis, and L.A. Bernacchi. Mustard cover cropping in potatoes: Dale Gies (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication. Washington State University Extension, Pullman. In press.

Yorgey, G. G., S. I. Kantor, K. M. Painter, L. A. Bernacchi, H. Davis, and R.D. Roe. 2016. Enhancing crop diversity: Steve and Becky Camp (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication 690. Washington State University Extension, Pullman.

Photo by Nita Robinson.

Yorgey, G. G., S. I. Kantor, K. M. Painter, H. Davis, and L. A. Bernacchi. 2016. Precision nitrogen application: Eric Odberg (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication 691. Washington State University Extension, Pullman.

Yorgey, G.G., S.I. Kantor, K. M. Painter, H. Davis, R. D. Roe, and L. A. Bernacchi. 2016. Flex cropping: Bill Jepsen (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication 681. Washington State University Extension, Pullman.

Yorgey, G., and C. Kruger, eds. 2017. *Advances in Sustainable Dryland Farming in the Inland Pacific Northwest*. Washington State University Extension Publication EM108, Pullman, WA. In press.

Yorgey, G. G., and A. McGuire. Strip tillage of onions: Lorin Grigg (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication. Washington State University Extension, Pullman. In review.

Yorgey, G. G., K. M. Painter, K. Borrelli, E. Brooks, and H. Davis. Deficit irrigation: Jake Madison (Farmer to Farmer Case Study Series). Pacific Northwest Extension Publication. Washington State University Extension, Pullman. In preparation.

Longitudinal grower survey guides research, underpins enterprise budgets

Contributed by Kate Painter, kpainter@uidaho.edu

Issue: Farmers across the diverse landscape of the inland Pacific Northwest face varying resources and resource constraints over time and space. Detailed information on the specific practices, costs, yields, profitability, and attitudes toward change of individual farmers is not generally available.

Action taken: A group of 47 growers selected for geographic location, history of university collaboration, innovative farming practices, and leadership roles agreed to participate in a longitudinal survey. For four years, we conducted personal, on-farm interviews with these growers. We gathered information on social, economic, agronomic, biotic, and climatic topics. We gathered detailed information on machinery, input usage, and field operations. Our unique approach allowed interdisciplinary scientists to add questions in each year of the survey. Our survey covered a variety of on-farm variation, as both 2011 and 2012 were much wetter than usual, while 2014 and 2015 were much drier than normal.

Results: Our project illustrated annual economic fluctuations due to differing levels of precipitation. We used the results to create baseline enterprise budgets for three distinct agroecological classes. Detailed information from our surveys helped other researchers understand how growers' practices differ across the region. Grower responses also guided project scientists in many areas of research, including technology usage, pests, and grower use of extension services. Growers are highly individual, and solutions for climate challenges need to reflect the diverse motivations and resources available to each grower in order to be both effective and acceptable.

Our enterprise budgets are available at: https://www.reacchpna.org/farm-enterprise-budgets

Results published in:

Kirby, E. M., W. L. Pan, D. R. Huggins, K. M. Painter, and P. Bista. 2017. Rotational diversification and intensification. In: Yorgey, G., and C. Kruger, (eds), *Advances in Sustainable Dryland Farming in the Inland Pacific Northwest*. Publication EM108. Washington State University Extension, Pullman, WA. In press.

A role for crop consultants in climate-change communication

Contributed by Leigh Bernacchi, labernacchi@gmail.com

Issue: Sharing climate change adaptation information and management practices with producers is a challenge for university extension.

Action taken: We conducted the first large-scale survey of agricultural producers' perspectives on climate change in the Pacific Northwest. The survey's findings led to our investigation of crop consultants' role in climate change communication. We interviewed crop insurance agents, chemical manufacturers, and consultants from multiple companies.

Results: Crop consultants and advisors can help bring about adaptation to climate change in the dispersed and diverse farming community. Whether they work with a private company or as independent contractors, they manage multiple farms' pest and nutrient applications and address any issues that arise throughout the year. They are in constant contact with growers, often working 80 hours per week and creating both short- and long-term plans (3 to 5 years).

All the consultants we interviewed had observed changes to climate in their lifetimes and feared drought in the rain-fed system, but younger consultants were more likely to attribute climate changes to human causes. Because of their intimate relationship with growers, they provide a communication pathway between the university's research programs and day-to-day grower questions. Crop consultants will continue to be an important target audience for extension in addressing climate change.

Results published in:

Bernacchi, L. A., and J. D. Wulfhorst. 2017. Crop consultants serving as "climate consultants": An Extension opportunity for climate change communication. *Journal of Extension*. In press.

Crop consultants pose for a photo in front of an Apache sprayer at Precision Agriculture Demonstration Day. Photo by Leigh Bernacchi.

Aaron Esser, WSU Extension specialist at Wilke Farm Field Day. Photo by Sylvia Kantor.

University Extension as a trusted source of climate-change information

Contributed by Leigh Bernacchi, labernacchi@gmail.com

Issue: Climate change, global warming, and the idea that humans could affect something as vast as our atmosphere are fraught with political, economic, ideological, and social connections. The challenge is to identify opportunities and barriers to climate change adaptation and mitigation among Pacific Northwest (PNW) cereal producers.

Action taken: To overcome barriers to climate change adaptation among PNW cereal growers, we studied their existing trusted relationships and resources for production management and climate change information through a large-scale mail survey of 900 producers.

Results: Trust is critical in any societal conversion to new ideas or adoption of new technologies. Our research has identified existing and novel pathways for reaching producers with climate change information.

Our survey first asked producers who they trust with respect to production management strategies. We found that they largely trust each other followed closely by crop advisors associated with a company.

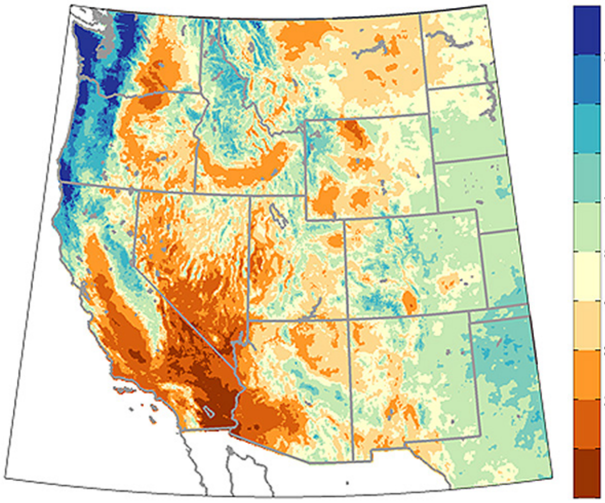
However, with respect to climate change information, we found that university Extension is their most trustworthy resource followed by conservation districts and crop consultants associated with a company.

Climate information presented online could be useful to growers. Producers use the Internet daily to access farm-related information, although they are less likely to use mobile applications to access this information. Our results suggest that university Extension can continue to be effective in informing producers about climate-change impacts to their production systems and can effectively use digital means of information delivery.

Results published in:

Borrelli, K. A., G. E. Roesch-McNally, J. D. Wulfhorst, S. D. Eigenbrode, G. G. Yorgey, C. E. Kruger, L. A. Bernacchi, L. L. Houston, and R. L. Mahler. Inland Northwest cereal producers' trust in sources of climate information and use of technology. *Natural Sciences Education*. In review.

Climate-Based Projections and Integration



Calendar year precipitation (units in millimeters) for 2015 across the western US from the gridMET dataset of Abatzoglou (2013).

Resolving historical and future climate data at local scales

Contributed by John Abatzoglou,
jabatzoglou@uidaho.edu

Issue: Climate provides a template for agricultural productivity and crop suitability. In dryland systems, for example, moisture availability is critically important in determining wheat yields and crop rotations. Changes in climate due to man-made climate change may impact the viability of dryland wheat farming. To best understand the impacts of climate variability and change on agricultural systems requires advancing methods for resolving both historical and future climate at local scales.

Action taken: We developed a historical gridded surface meteorological dataset, a downscaled season forecast dataset, and a statistical downscaling method to translate coarse-resolution climate model output to local scales to facilitate climate impacts assessments.

Results: The surface gridded meteorological dataset provides relatively high-resolution data on surface weather variables from 1979 through the present, updated daily. The downscaled seasonal forecast dataset provides place-based forecasts of temperature and precipitation for the next one to seven months from seven climate models. The statistical downscaling method allows for place-based projections of climate across multiple variables that are important for agricultural, hydrological, and ecological modeling, including temperature, precipitation, humidity, winds, and solar radiation.

Our datasets have been extended for use across the contiguous US and are being used by other coordinated agricultural projects (CAPs), U.S. Geological Survey climate science centers, U.S. Department of Agriculture climate hubs, the U.S. Forest Service, and many individual researchers to better understand climate variability, change, and impacts.

We have developed numerous visualization and decision-support tools hosted through the Northwest Knowledge Network that disseminates this information. These websites include:

Historical data:
http://climate.nkn.uidaho.edu/METDATA/

Downscaled seasonal forecasts:
http://climate.nkn.uidaho.edu/downscaledForecast/

Downscaled projections:
http://climate.nkn.uidaho.edu/MACA/

REACCH climate tools:
http://climate.nkn.uidaho.edu/REACCH/climateTools.php

Results published in:

Abatzoglou, J. T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology* 33: 121–131.

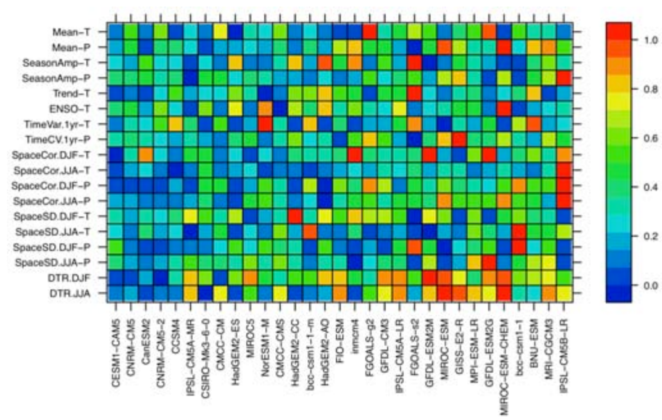
Abatzoglou, J. T., and T. J. Brown. 2012. A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology* 32: 772–780.

Barbero, R., J. T. Abatzoglou, and K. C. Hegewisch. 2017. Evaluation of statistical downloading of North American Multi-Model Ensemble hindcasts over western USA. *Weather and Forecasting*. Accepted.

Evaluating climate-model credibility

Contributed by John Abatzoglou,
jabatzoglou@uidaho.edu

Issue: The number of climate models available results in a large amount of potentially useful information for assessing regional climate impacts. However, some of the models may be better suited than others to providing credible projections about future



Matrix of climate model credibility adapted from Rupp et al. (2013). The colors show the relative error for each performance metric (listed along the y-axis) and for each climate model (listed along the x-axis), where the better-performing models have lower errors as indicated by cooler shades. The ordering of climate models along the x-axis corresponds to the ranking of total relative error across all metrics, listed from the most credible (left) to least credible (right).

climate. Formally evaluating the credibility of models provides an objective approach for selecting a subset of models for regional climate-change assessments.

Action taken: We developed a statistical approach for comprehensively evaluating the credibility of climate models for simulating climate characteristics of the northwestern US. In addition, we sought models flexible enough to be applied to other regions.

Results: We developed a set of performance metrics for capturing seasonal and spatial patterns of temperature and precipitation across the northwestern US and implemented them for over 40 climate models. From the broader set of models, we selected those with higher relative credibility. Our evaluation has been adopted by numerous studies that have used climate models in the region and has assisted in the selection of climate simulations for the southwestern and southeastern US.

Results published in:

Rupp, D. E., J. T. Abatzoglou, K. C. Hegewisch, and P. W. Mote. 2013. Evaluation of CMIP5 20th century climate simulations for the Pacific Northwest USA. *Journal of Geophysical Research-Atmospheres* 118(19): 10884–10906.

Will the distribution of dryland cropping systems in the inland Pacific Northwest be affected by climate change?

Contributed by Claudio Stöckle, stockle@wsu.edu

Issue: The dryland agricultural region of the inland Pacific Northwest (PNW) includes northern ID, eastern WA, and northern OR. REACCH scientists have used U.S. Department of Agriculture crop data from 2007 to 2011 to classify the inland PNW dryland area into agroecological classes based on the percentage of fallow land. Crop-fallow (CF) has 40% or more fallow, annual crop-fallow transition (CCF) has 10 to 40% fallow, and annual cropping (CC) has less than 10% fallow. Climate change in the next century will potentially affect water use and yields of water-limited dryland crops. Will these changes affect the distribution of agroecological classes, and thus of cropping intensity in the region?

Action taken: To understand the interaction between climate change and increasing atmospheric carbon dioxide (CO_2) in the inland PNW and its impact on regional wheat-based systems, we used computer simulations that combined cropping systems models with weather generated from projections by 12 global circulation models. The models considered two levels of increasing atmospheric CO_2 and associated warming—low, RCP4.5, and high, RCP8.5, where RCP is the Representative Concentration Pathway of atmospheric CO_2. We developed projections of future crop yields and water use for this century and compared them with baseline yields for the period 1979 to 2010. Based on this simulated data, we projected the distribution of agroecological classes for later in this century.

Results: Figure 1 shows the spatial distribution of agroecological classes during historical (1979 to 2010) and future (2030s, 2050s, and 2070s) periods. Figure 2 shows the average percentage

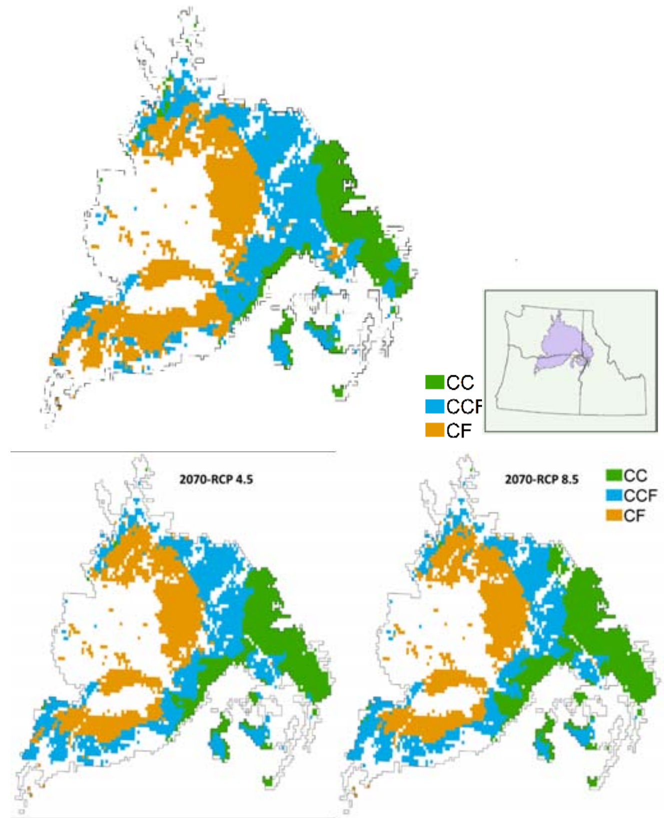


Figure 1. Historical (1979 to 2010) and future (2055 to 2085) agroecological classes.

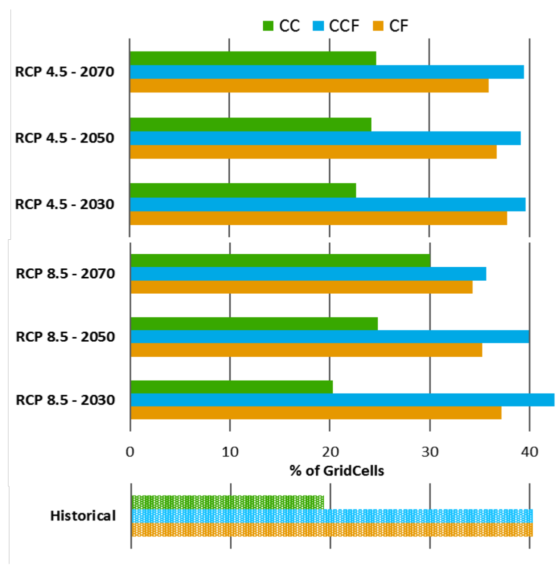


Figure 2. Average percentage of cells in CF, CCF, and CC agroecological classes during historical (1897 to 2010) and future (2030s, 2050s and 2070s) periods, considering RCP4.5 and RCP8.5 atmospheric CO_2 scenarios.

of cells in CF, CCF, and CC agroecological classes, considering RCP4.5 and RCP8.5 atmospheric CO_2 scenarios.

Because simulations projected increased water-use efficiency and wheat productivity for most of the century, the fraction of the regional area occupied by CC (the most-intense cropping system) tended to increase, while CF (the lowest-intensity cropping

continued next page

Climate-Based Projections and Integration

system) decreased in all future periods and RCP scenarios. The area under transitional CCF remained basically the same. These results are based on average values, but the picture is essentially the same if we use yields for 70% probability of exceedance (better or similar yields are obtained 70% of the years), which are more representative of farmers' decisions that minimize risk.

Results published in:

Karimi, T., C. O. Stöckle, S. Higgins, and R. L. Nelson. Projected dryland cropping system shifts in the Pacific Northwest in response to climate change. *Frontiers in Ecology and Evolution*. In review.

Stöckle, C. O., S. Higgins, R. Nelson, J. Abatzoglou, D. R. Huggins, W. L. Pan, T. Karimi, J. Antle, S. Eigenbrode, and E. Brooks. Evaluating opportunities for an increased role of winter crops as adaptation to climate change in dryland cropping systems of the U.S. Inland Pacific Northwest. *Climatic Change*. In review.

Wheat is projected to do better under climate change than normally assumed

Contributed by Claudio Stöckle, stockle@wsu.edu

Issue: The long-term sustainability of wheat-based dryland cropping systems in the inland Pacific Northwest (PNW) depends on how these systems adapt to climate change. Climate models project warming in the region, with drier summers and slight increases in winter precipitation. These conditions are likely to decrease yields, particularly of spring crops, although adaptations such as earlier planting will help delay negative effects. However, the rising levels of atmospheric carbon dioxide (CO_2) that are driving global warming also have direct beneficial effects on crops, promoting crop growth and improving water-use efficiency. This effect, sometimes referred to as "CO_2 fertilization," might mean that the future of dryland agriculture is better than it is assumed to be when considering climate warming alone.

Action taken: To understand the interaction between climate change and increasing atmospheric CO_2 in the inland PNW and its impact on regional wheat-based systems, we used computer simulations that combined cropping systems models with weather generated from projections by 12 global circulation models. The models considered two levels (low and high) of increasing atmospheric CO_2 and associated warming (higher warming associated with higher atmospheric CO_2). We developed projections of future crop yields for this century and compared them with baseline yields for the period 1979 to 2010.

Results: Despite the common assumption of negative climate-change impacts on agricultural production, computer simulations indicated that wheat productivity will actually increase in the inland PNW for most of the century. Higher winter and spring temperatures should benefit the growth of winter crops and allow for earlier planting of spring crops. Earlier maturity of both types of crops would help avoid the more extreme and damaging summer heat.

Considering only climate change (temperature increase and some change in precipitation but no CO_2 fertilization effect), yields were projected to remain constant throughout the century at the lower level of warming but to first increase and then decline below baseline values at the higher level of warming. When CO_2 fertilization effects were included, wheat yields for the lower levels of atmospheric CO_2 and warming were projected to have a small and steady increase until the end of the century, but at higher levels of atmospheric CO_2 and warming, wheat yields were projected to increase up to midcentury and then decline by the end of the century to levels generally similar to baseline.

Results published in:

Ahmed, M., C. O. Stöckle, R. Nelson, and S. Higgins. Assessment of climate change impact on winter wheat in the US Pacific Northwest using a multi-model ensemble. *Frontiers in Ecology and Evolution*. In review.

Karimi, T., C. Stöckle, S. Higgins, and R. Nelson. Climate change and dryland wheat systems in the US Pacific Northwest. *Agricultural Systems*. In review.

Karimi, T., C. O. Stöckle, S. Higgins, and R. L. Nelson. Projected dryland cropping system shifts in the Pacific Northwest in response to climate change. *Frontiers in Ecology and Evolution*. In review.

Stöckle, C. O., S. Higgins, R. Nelson, J. Abatzoglou,D. R. Huggins, W. L. Pan, T. Karimi, J. Antle, S. Eigenbrode, E. Brooks. Evaluating opportunities for an increased role of winter crops as adaptation to climate change in dryland cropping systems of the U.S. Inland Pacific Northwest. *Climatic Change.* In review.

Stöckle, C. O, R. L. Nelson, S. Higgins, J. Brunner, G. Grove, R. Boydston, M. Whiting, and C. Kruger. 2010. Assessment of climate change impact on eastern Washington agriculture. *Climatic Change* 102:77–102.

Photo by Brad Stokes.

Regional estimation of crop water use and yields based on remote sensing and simple crop growth algorithms

Contributed by Claudio Stöckle, stockle@wsu.edu

Issue: From the perspective of global food security under population increase and climate change, regional monitoring of cropping systems, water use, and crop yields are of significant interest for land management, food pricing, and trading policies. Monitoring data are difficult to obtain on a real-time or near-real-time basis at large scales, however, since crop models, statistical models, and other similar approaches are either difficult to implement and parameterize or include sizeable uncertainty. Remote sensing data offer significant promise for regional assessment and crop yield forecasting if image processing can be enhanced by software development and linked with simple crop-modeling algorithms.

Action taken: We have adapted and evaluated METRIC for use in the dryland area of the inland Pacific Northwest. This remote sensing-based method uses an energy balance approach to estimate actual crop evapotranspiration (ET_a = sum of crop water use and soil water evaporation) without having to specifically account for hydrological, soil water, and crop processes. We compared estimations of ET_a with eddy covariance measurements at four REACCH study sites, across three seasons and five different crops, and with annual precipitation ranging from 247 to 680 millimeters. After METRIC evaluation, we linked simple crop-growth algorithms and topsoil water balance to 30 x 30 meter resolution estimates of ET_a to calculate crop water use, seasonal biomass production, and grain yields.

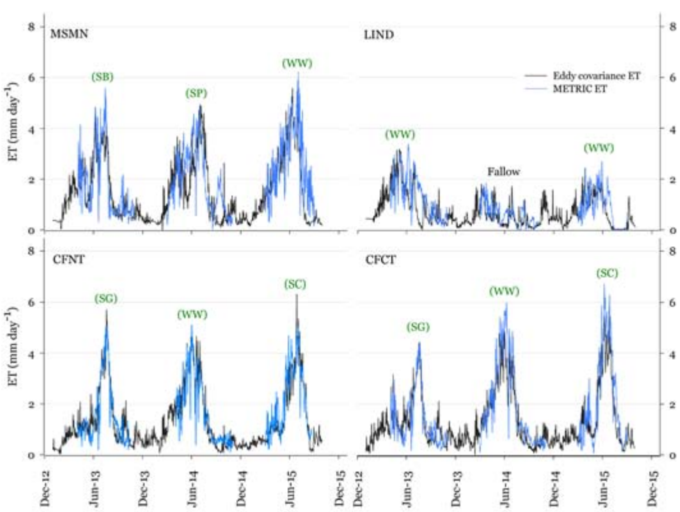


Figure 1. Daily time-step comparison of METRIC and EC evapotranspiration at four REACCH sites (MSMN, LIND, CFNT, and CFCT) and three growing seasons. Abbreviations: SB=Spring Barley, SP=Spring Pea, WW=Winter Wheat, SG=Spring Garbanzo, SC=Spring Canola.

Results: Remote sensing-based METRIC estimates of ET_a compared well with on-the-ground measurements obtained with eddy covariance instrumentation, with standard errors ranging from 0.3 to 0.5 millimeters per day for satellite overpass days and 0.4 to 0.8 millimeters per day for other days, with the higher bias generally associated with fallow periods. The daily progression of METRIC ET_a at all sites and among all crops reasonably matched eddy covariance measurements without any calibration for specific crops or sites (Figure 1).

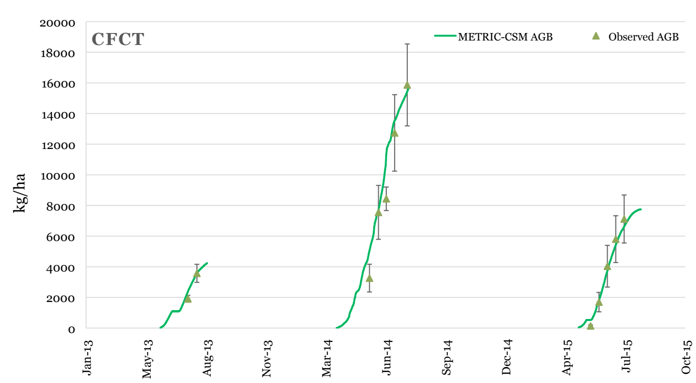
Our evaluation found that METRIC can estimate ET_a in dryland areas, where crops are often limited by water, with similar accuracy to that reported for irrigated crops. Combining METRIC ET_a with simple crop-growth and topsoil water balance algorithms resulted in seasonal aboveground estimates that compared well with direct measurements at all sites, as shown in Figure 2 for one of the sites evaluated. These are very encouraging preliminary results that may lead to the development of reasonably accurate regional assessments of evapotranspiration and crop yields forecasting.

Results published in:

Khan, M.A., C. O. Stöckle, R. Nelson, and J. Chi. Estimating biomass production and yield of dryland crops using remote sensing and a simple crop model. *Agricultural and Forest Meteorology*. In review.

Khan, M. A., C. O. Stöckle, T. Peters, J. C. Adam, R. G. Allen, R. Trezza, B. Lamb, and J. Chi. Evaluation of METRIC for estimation of actual evapotranspiration from dryland agricultural systems in eastern Washington State. *Remote Sensing of Environment*. In review.

Figure 2. Comparison of remote sensing–simple crop growth algorithms and measurements of seasonal progression of aboveground biomass (AGB) accumulation for three crops at the CFCT site.



Climate-Based Projections and Integration

Defining agroecological classes for assessing land use dynamics

Contributed by Dave Huggins, dhuggins@wsu.edu

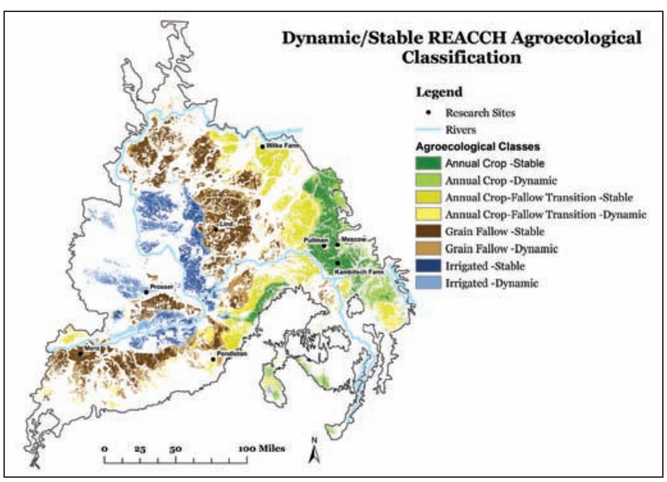
Issue: Defining agroecological classes (AECs), which classify land use, cover, and changes through time, enables researchers, stakeholders, students, the public, and policy makers to acquire a more holistic understanding of agriculture and climate change. AECs are intended to be part of a prescription 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.

Action taken: We originated the concept of Dynamic AECs, developed methodology for quantifying AECs, and produced regional maps of Dynamic AECs that show the major dryland cropping systems of the inland Pacific Northwest. The Dynamic AECs use the annual NASS Cropland Datalayer and quantify annual and long-term changes in major cropping systems, crops, and overall land use.

Results: Many REACCH investigators have used the AEC concept to frame their research and to give it agricultural context. They have documented changes in cropping systems and in specific crops on an annual basis. Regions where AECs were stable or dynamic have been identified, enabling hypothesis development to further understand land-use change.

Results published in:

Huggins, D. R., H. Kaur, R. Rupp, and J. Abatzoglou. Dynamic agroecological classes for assessing land use change in the Inland Pacific Northwest. *PLOS ONE*. In review.



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

Changing bioclimatic drivers increase future uncertainty of agroecosystem classes

Contributed by Dave Huggins, dhuggins@wsu.edu

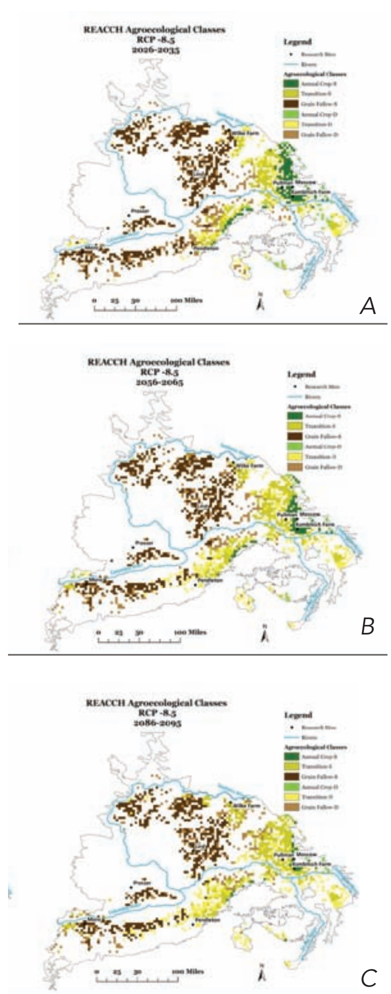
Issue: Future climate change may result in major shifts in the location and extent of dryland agricultural systems, currently defined as agroecological classes (AECs).

Action taken: We assessed the relationship between the location and extent of the REACCH region's current AECs and different bioclimatic variables such as evapotranspiration and precipitation. Using the predictive relationship between bioclimatic variables and AECs, we assessed how current AECs would shift if we imposed future climate projections onto our current AECs.

Results: We found that climate change could cause substantial increases in the geospatial extent of annual fallow (no crop grown for a year) at the expense of annual cropping. If the extent of fallow does increase in the future, it would negatively impact cropping system diversification and intensification, soil organic matter, and soil vulnerability to erosion processes.

Results published in:

Kaur, H., D. Huggins, R. Rupp, J. Abatzoglou, and J. Reganold. Changing bioclimatic drivers increase future uncertainty of agroecosystem classes of the Northwest, USA. *Frontiers in Ecology and Evolution*. In review.



Projected shifts in REACCH agroecological classes RCP-8.5 under different future scenarios: A) years 2026-2035, B) years 2056-2065, and C) years 2086-2095.

Projected changes in cold hardiness zones of perennial crops

Contributed by Lauren Parker, lparker@uidaho.edu

Issue: Climate is one factor that shapes the geographic zones suitable for crop cultivation. Among the limiting factors for cold-intolerant perennial agriculture are overwinter temperatures. Climate change will likely change the geography of where cold-intolerant crops can be cultivated.

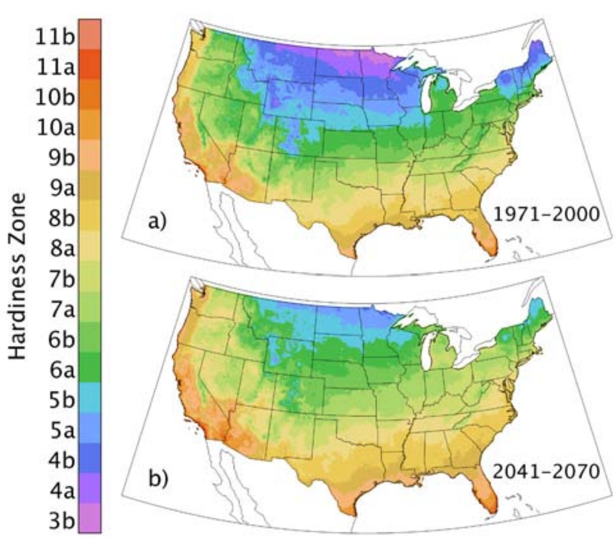
Action taken: We used downscaled climate projections for the mid-21st century to calculate changes in cold hardiness zones as defined by the average minimum temperature each winter.

Results: Amplified warming of approximately 40% was projected for the coldest night of the winter compared to average winter temperatures across much of the US. This results in wholesale shifts in cold hardiness zones by approximately one zone by the mid-21st century, equivalent to an average northward shift of current cold hardiness zones by 60 miles. While this may increase the potential for cultivating cold-intolerant crops farther north, it could also increase pressure from invasive species and pests with subsequent impacts on agricultural economics and adaptation efforts.

We developed an interactive map of these projections, which is accessible at: http://climate.nkn.uidaho.edu/REACCH/decisionTools.php

Results published in:

Parker, L. E., and J.T. Abatzoglou. 2016: Projected changes in cold hardiness zones and suitable overwinter ranges of perennial crops over the United States, *Environmental Research Letters* 11: 034001.



The shift in USDA cold hardiness zones projected by global climate model outputs from 1979-2000 to mid-21st century (2040-2069).

Training Scientists and Educators

Informing the future: High school and fourth-grade curricula

Contributed by Kat Wolf, kwolf@uidaho.edu

Issue: The public has general misconceptions about agriculture, climate change, and the relationship between the two.

Action taken: REACCH developed curricula aligned with both state and Common Core standards for high school and elementary classrooms. The semester-long curricula address the intersection of agriculture and climate change through interactive lessons and hands-on labs.

Results: Informative, easy-to-use, downloadable high school and fourth-grade curricula will allow teachers to integrate agricultural and climate change topics into their classrooms. A total of 76 teachers were trained to carry out agriculture and climate change lessons and laboratories with their students during summer workshops. If each teacher has a total of 25 students per year, we will reach approximately 1,900 students per year. In ID, OR, and WA, high school curriculum will be sent to 1,924 science teachers and 528 agriculture teachers. The intermediate primary curriculum will be sent to 4,328 teachers. Additionally, 16 teacher trainee departments at higher education instutions will receive the curricula.

The students and teachers also shared their thoughts on climate change utilizing the Six Americas survey. Of students completing a post-test following instruction using the REACCH curriculum in 2015, 84.5% felt that climate change was occurring, an increase of 5.2%. Of those students, 48.1% were either very or extremely sure.

Both curricula will provide teachers with accurate information regarding climate change and agriculture, and the inclusion of both science and agriculture teachers in our workshops will help spread the use of agriculture-based examples and knowledge across science, technology, engineering, and mathematics (STEM) fields.

REACCH curricula are available at:
https://www.reacchpna.org/education

HOIST high school students beta testing a REACCH curriculum unit. Units use accurate and current scientific content to enhance future generations' knowledge of sustainable agriculture.

Training Scientists and Educators

A hands-on experience: Undergraduate internships

Contributed by Jodi Johnson-Maynard, jmaynard@uidaho.edu

Issue: The number of jobs in agricultural fields is expected to grow faster than the number of students being trained in four-year degree programs. This trend suggests a lack of future professionals to fill critical jobs within the agricultural sciences. In addition, student diversity in agricultural fields is extremely low.

Action taken: We provided internships for undergraduates to complete independent research in faculty laboratories and provided professional development with the goal of encouraging students to continue in science, technology, engineering, and mathematics (STEM) fields. We made efforts to ensure diversity within our internship cohorts. REACCH faculty also participated in HOIST (Helping Orient Indian Students and Teachers into STEM) programming at the University of Idaho to encourage diverse students to consider careers in the agricultural sciences.

Results: Seventy-five undergraduates from across the US received intensive, hands-on research experience and training in interdisciplinary communication and collaboration and in how to apply to and succeed in graduate school. These internships helped prepare students for graduate work through dynamic, hands-on research and provided them with greater knowledge of career opportunities in agricultural fields. The students participated in seminars and workshops, culminating in final presentations where they shared their work with the larger scientific community.

In 2013, 56% of our interns were female and 25% were ethnic minorities (Hispanic and American Indian). Over the last three years of the REACCH internship program, 68% of the students were female and 12% were ethnic minorities. In addition to the internship program, several REACCH faculty and graduate students conducted workshops during the six-week HOIST program to enhance understanding of climate change and agriculture among the high school participants.

REACCH interns participated in several summer field days. In addition to research products, intern teams developed extension/education products. Interaction with stakeholders highlighted the importance of actionable science.

Meeting the future food needs of a growing population requires preparing students for professional careers in agriculture. Today's agricultural workers require workforce development training to implement the scientific practices and advanced technologies needed to remain competitive in today's market.

Graduate interdisciplinary education

Contributed by Jodi Johnson-Maynard, jmaynard@uidaho.edu

Issue: Graduate education in the sciences is often isolated and very discipline oriented. Social, political, and environmental complexities and interactions require that future scientists work across disciplines to solve the complex problems facing agriculture.

Action taken: We have supported 63 graduate students and post-doctoral fellows (40 fully funded). We have taken an interdisciplinary approach to graduate education by facilitating graduate student retreats and providing professional development. These retreats encourage project-wide synergy and communication on cross-disciplinary and interdisciplinary aspects of the project.

Results: Team-based, integrative training and professional development for REACCH graduate students increases the likelihood that they will continue to work in the broad field of agriculture. Of graduating PhD students, 33% obtained assistant professor positions at non-REACCH institutions; the other 66% are currently employed as post-doctoral researchers within their fields. Two post-doctoral researchers and one REACCH staff member are now assistant professors at non-REACCH institutions. Furthermore, results of an exit survey suggest that participating in REACCH research and professional development helped students gain employment.

Long-Term Experiments

Crop residue and nitrogen management effects on soil organic matter

Contributed by Stephen Machado, stephen.machado@oregonstate.edu

Issue: Soil organic matter is a key indicator of soil health because of its influence on soil structure, aggregate stability, water infiltration, water holding capacity, soil biological activity, cation exchange capacity, and pH buffering and amelioration. Since cultivation began in the 1800s, up to 60% of soil organic matter has been lost from wheat–fallow lands of the Pacific Northwest (PNW). Soil organic matter has become depleted because of limited biomass production, which is due to low precipitation and fallowing every other year. Improving soil health by building up soil organic matter is necessary for enhancing crop productivity and sustainable agriculture.

Action taken: We used data from the ongoing long-term experiments at the Oregon State University Columbia Basin Agricultural Research Center near Pendleton to study soil organic matter depletion and the effects of burning and nitrogen application.

Results: We have over 80 years of data indicating that the predominant wheat–fallow cropping system depleted up to 63% of soil organic matter and 26% of nitrogen from the 0- to 60-centimeter soil depth profile when compared to an adjacent grass pasture, except where cattle manure was applied biennially at about 22 megagrams per hectare. Fall burning was most detrimental and depleted soil organic matter at the rate of 0.64 megagrams per hectare per year. Addition of up to 90 kilograms per hectare of nitrogen did not stop soil organic matter depletion in the wheat–fallow systems. Soil organic matter loss in treatments where pea vines were added back to the soil, although more than the loss under manure treatments, was less than under treatments receiving nitrogen.

Moro Long-term experiment (established in 2003) at the Oregon State University, Columbia Basin Agricultural Research Station, Moro, OR. Photo provided by Stephen Machado.

In another study that started in 1963, soil organic matter was maintained in wheat–pea cropping systems, particularly under reduced- and no-till systems. Reduction in tillage, application of low C:N ratio residues (e.g., pea vines), and elimination of burning can improve sustainability of winter wheat production in the summer-fallow region of the PNW.

Results published in:

Bista, P., S. Machado, R. Ghimire, S. J. Del Grosso, and M. Reyes-Fox. 2016. Simulating soil organic carbon in a wheat-fallow system using the Daycent Model. *Agronomy Journal* 108:2554-2565.

Ghimire, R., and S. Machado. 2015. Long-term crop residue and nitrogen management effects on soil profile carbon and nitrogen in wheat–fallow systems. *Agronomy Journal* 107: 2230–2240.

Machado, S. 2011. Soil organic carbon dynamics in the Pendleton long-term experiments: Implications for biofuel production in Pacific Northwest. *Agronomy Journal* 103:253–260.

Winter wheat-summer fallow rotation. Moro, OR. Photo provided by Stephen Machado.

No-till cropping systems can replace summer fallow in north-central Oregon and south-central Washington

Contributed by Stephen Machado, stephen.machado@oregonstate.edu

Issue: Annual cropping, necessary for soil organic matter maintenance or buildup, is difficult to implement in most parts of north-central OR and south-central WA, where annual precipitation is less than 280 millimeters. Most wheat growers in these regions are still practicing the traditional winter wheat–summer fallow rotation using some form of tillage. Previous studies have shown that this cropping system depletes soil organic matter, exacerbates soil erosion, and is not biologically sustainable. Some growers remain skeptical about alternative cropping systems such as the wheat–fallow system using no-till or chemical fallow

continued next page

Long-Term Experiments

that have the potential to alleviate the negative impacts of the traditional wheat–fallow system.

Action taken: To inform growers transitioning from the traditional winter wheat–summer fallow system to no-till systems, we established a long-term experiment in the 2003–04 crop year to identify no-till fallow systems and annual cropping systems that could replace the traditional wheat–fallow system without sacrificing grain yield. After six years of study, average grain yields of winter wheat in the no-till winter wheat–chemical fallow rotation (3.43 megagrams per hectare) and winter wheat–spring barley–chemical fallow rotation (3.76 megagrams per hectare) were not significantly different from wheat grain yields under the traditional wheat–fallow rotation (3.56 megagrams per hectare). No-till fallow systems continued to yield more than traditional fallow systems in the 5-year period that followed. Water use efficiency was very similar among the three fallow systems. Results also show that no-till annual cropping of winter wheat, spring wheat, and barley, although risky, can be practiced in this region. Weeds were easier to control in the annual cropping rotation compared to other rotations.

Results: Given the benefit of no-till systems to soil conservation, adoption of no-till winter wheat–chemical fallow or the more-intensified winter wheat–spring barley–chemical fallow rotation in place of the traditional winter wheat–summer fallow system is recommended. Annual cropping of spring wheat and spring barley under no-till is also recommended if deemed profitable. Annual cropping was observed to increase soil surface residues and soil organic matter, factors essential for enhancing grain yields, supporting agricultural sustainability, and developing climate-resilient cropping systems.

Results published in:

Machado. S., L. Pritchett, and S. Petrie. 2015. No-tillage cropping systems can replace traditional summer fallow in north-central Oregon. *Agronomy Journal* 107:1863–1877.

Smiley, R. W., S. Machado, J. A. Gourlie, L. C. Pritchett, G. P. Yan, and E. E. Jacobsen. 2013. Effects of crop rotations and tillage on *Pratylenchus* spp. in the semiarid Pacific Northwest United States. *Plant Disease* 97: 537-546.

Predicting soil organic matter trends

Contributed by Stephen Machado,
stephen.machado@oregonstate.edu

Issue: Soil organic matter is the foundation of healthy soil and agricultural sustainability. Changes in soil organic matter, however, often take more than 10 years to become evident, and by then considerable soil degradation may have occurred. At the Columbia Basin Agricultural Research Center, OR, it has taken between 20 and 80 years to see substantial changes in soil organic matter. The ability to predict management effects on soil organic matter dynamics, therefore, is a prerequisite to designing resilient and sustainable cropping systems under a changing climate.

Action taken: Using data from an 80-year-old crop residue experiment, we used the DAYCENT model to predict trends in grain yield (r=0.93), residue yield (r=0.95), and soil organic matter (r=0.99) from 1931 to 2010. We then projected the effects of conventional tillage and no-till on soil organic matter into the future.

Results: The model projected that conventionally tilled wheat–fallow systems, except where manure was added, would lose 866 to 2192 grams soil organic carbon per square meter (g C/m^2) (58% of soil organic matter) between 1931 and 2080. The manure treatment would add 496 g C/m^2 soil organic carbon during the same period. Conversion from current conventional tillage practices to no-till from 2011 onward, however, would minimize soil organic matter loss by 17% to 47% under different wheat–fallow systems. No-till conversion in addition to the manure treatment would increase soil organic matter by more than 300%. Adoption of a no-till system and the addition of organic amendments can improve the long-term sustainability of dryland wheat–fallow systems.

Results published in:

Bista, P., S. Machado, R. Ghimire, S. J. Del Grosso, and M. Reyes-Fox. 2016. Simulating soil organic carbon in a wheat-fallow system using the Daycent model. *Agronomy Journal* 108: 2554–2565.

No-till field, Moro, OR. Photo provided by Stephen Machado.

Prilled biochar from Walking Points Farms. Photo provided by Howard Boyte, CEO, Walking Point Farms LLC.

Biochar builds soil organic matter and raises soil pH

Contributed by Stephen Machado, stephen.machado@oregonstate.edu

Issue: Up to 60% of soil organic matter has been lost since the 1800s, when cultivation started in wheat–fallow lands of the Pacific Northwest. Soil organic matter has become depleted because of limited biomass production, which is due to low precipitation and fallowing every other year. In addition, the continued use of ammonium-based fertilizers has increased soil acidity to less than pH 5.0 in the top 15 centimeters of soil. Soil pH below 5.2 interferes with wheat growth, biomass production, and yield. Increased soil organic matter and favorable pH levels (pH 6 to 7) are essential for improved crop productivity and sustainable agriculture under a changing climate.

Action taken: Biochar, charcoal produced from pyrolysis and resistant to decomposition, has the potential to improve soil health. Adding biochar to soil sequesters carbon that would otherwise be lost to the atmosphere as carbon dioxide through burning or natural decomposition, where it would contribute to global warming. We evaluated the effects of biochar derived from forest wastes on crop yields, soil pH, and nutrient dynamics. Biochar was applied to field plots under a winter wheat–spring pea rotation and to soil samples with or without fertilizer in a greenhouse experiment.

Results: In the field, application of biochar increased grain yield, and the yield increase has persisted for three years even without further biochar applications. Biochar increased pH by 0.42 units (5.76 to 6.18) but did not influence other nutrients. In the greenhouse study, biochar increased wheat shoot biomass and root biomass as well as soil pH. Applying biochar to soil samples also increased phosphorus, potassium, and sulfur, but not nitrate and ammonium.

Results indicate that biochar has the potential to increase crop yields from wheat and spring peas while sequestering carbon. Increasing pH may have increased nutrient use efficiency, resulting in higher crop yields. The positive effects from biochar have persisted for three years, and the study continues to monitor yield without any further applications of biochar.

Results published in:

Manuscript under preparation.

Building soil organic matter with biosolids

Contributed by Bill Pan, wlpan@wsu.edu

Issue: Building soil organic matter levels in the inland Pacific Northwest has proven to be challenging in our traditional cropping systems. The one management factor linked to substantial soil organic matter increases, as documented in long-term trials at Pendleton, OR, is the addition of organic amendments such as animal manure.

Action taken: We conducted a comprehensive review of biological soil amendment research. In addition, we analyzed soil samples from a 20-year experiment conducted near Okanogan, WA, where a wheat–fallow system has been fertilized with either King County, WA, biosolids or commercial anhydrous ammonia. We analyzed archived soil, plant, and biosolids samples to assess carbon and nitrogen balances in the system over 20 years.

Results: Total soil organic carbon and nitrogen more than doubled over 20 years during biosolids application, while sufficiently fertilizing the wheat–fallow system. Anhydrous ammonia mostly contributed to grain nitrogen production. Gains in soil organic matter included stable organic matter fractions, providing further evidence that adding organic amendments like biosolids should be credited as an effective way to sequester carbon and reduce greenhouse gas emissions. Studies of long-term biosolids application on sequestration of carbon and nitrogen in other systems such as perennial grass pastures are continuing beyond REACCH.

Results published in:

Pan, W. L., L. E. Port, Y. Xiao, A. I. Bary, and C. G. Cogger. Soil carbon and nitrogen fractionation and balances during long-term biosolids applications to semi-arid wheat-fallow. *Soil Science Society of America Journal*. Submitted.

Yorgey, G., W. Pan, R. Awale, and S. Machado. Soil amendments research in dryland systems of the inland Pacific Northwest. In: Yorgey, G., and C. Kruger, (eds.), *Advances in Sustainable Dryland Farming in the Inland Pacific Northwest*. Washington State University Extension. In press.

Young, L., and B. Pan. 2015. Soil carbon and nitrogen fractionation following biosolids application. In Borrelli et al. (eds.), *Regional Approaches to Climate Change for Northwest Agriculture: Climate Science Northwest Farmers Can Use*. pp. 28–29.

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

Long-Term Experiments

Cook Agronomy Farm LTAR site: Knowledge-intensive precision agroecology

Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: Long-term, transdisciplinary agricultural research is essential if agriculture is to meet multiple, diverse societal goals including food supply; climate change adaptation and mitigation; bioenergy; water, air, and soil quality; and biodiversity.

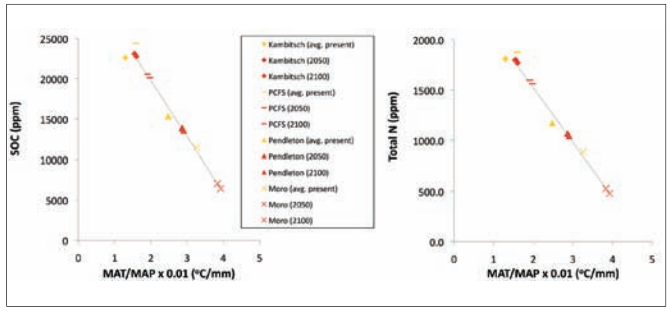
Action taken: In 2011, we responded to a U.S. Department of Agriculture (USDA) request for information regarding our eligibility to be part of a national Long-term Agroecosystem Research (LTAR) Network. The REACCH project, building on regional research partnerships, was seen as a major example of capacity to conduct long-term, transdisciplinary research.

Results: In 2011, USDA designated the Washington State University R. J. Cook Agronomy Farm as one of 10 sites within the Long-Term Agroecosystem Research (LTAR) Network, and in 2014 the farm received annual base funding for this effort. The funded LTAR will provide a cornerstone for supporting transdisciplinary research and partnerships, and will increase the region's competitive capacity to pursue a rich, grower-oriented research portfolio and to support graduate education and outreach efforts beyond REACCH.

Results published in:

Published data and articles are available at https://ltar.nal.usda.gov/

USDA's Long-Term Agroecosystem Research (LTAR) Network.



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

Climate change could negatively impact soil organic matter

Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: Predicted future climate scenarios for the inland Pacific Northwest (PNW), including warmer temperatures relative to precipitation levels, could negatively impact soil organic matter and associated soil health.

Action taken: Using long-term experiments throughout the dryland cropping region of the inland PNW, we assessed the relationship between soil organic carbon and the climate ratio—mean annual temperature divided by mean annual precipitation—as well as cropping intensity and soil disturbance. We also calculated future projections of the climate ratio to assess climate change impacts on soil organic carbon.

Results: We discovered a strong relationship between soil organic carbon and the climate ratio, where soil organic carbon declines as the climate ratio increases. The climate ratio was the dominant driver of soil organic carbon compared to both cropping system intensity and soil disturbance. Using future climate projections, we calculated that the climate ratio would increase throughout the region in response to climate change. Therefore, climate change could reduce overall soil organic carbon levels throughout the region. If this occurs, future soil health within the region would also decline.

Results published in:

Morrow, J. G., D. R. Huggins, and J. P. Reganold. Climate change predicted to negatively influence surface soil organic matter of dryland cropping systems in the inland Pacific Northwest, USA. *Frontiers in Ecology and Evolution*. In review.

Assessing soil health of long-term agricultural studies

Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: Monitoring soil health is an important component of any land management system and is likewise important for assessing agricultural sustainability. Currently, soil health assessments are expanding to consider more biological measures of soil health in addition to chemical and physical measurements. However, the utility of new soil health measurements needs to be assessed for the inland Pacific Northwest (PNW).

Action taken: We measured soil biological, chemical, and physical properties at long-term experiments throughout the dryland cropping region of the inland PNW. We evaluated these soil health metrics using the following seven criteria as a framework to judge their effectiveness: (1) evidence based, (2) sensitive to change, (3) logistically feasible, (4) cost effective, (5) accurate and precise, (6) performance, and (7) valued for management decisions.

Results: We found that biological measurements were much more variable than chemical and physical measurements, and in some cases were not sensitive enough to distinguish differences between long-term management practices such as no-tillage and cropping system intensification. Consequently, biological tests as well as other new tests need to be carefully assessed to determine their usefulness as soil health measurements. Based on our seven criteria to gauge soil health metrics, permanganate oxidizable carbon scored the highest and should be considered for soil health assessments in the inland PNW.

Results published in:

Morrow, J. G., D. R. Huggins, L. A. Carpenter-Boggs, and J. P. Reganold. 2016. Evaluating measures to assess soil health in long-term agroecosystem trials. *Soil Science Society of America Journal* 80(2): 450-462.

Photo by Alex Garland.

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

Conservation management effects on soil organic matter

Contributed by Dave Huggins, dhuggins@wsu.edu

Issue: Conversion of native lands to agricultural production has resulted in losses of soil organic carbon ranging from 20% to 60% within 40 to 50 years. Although adoption of practices such as conservation tillage, intensification of cropping, and application of organic amendments can at least partially restore soil organic carbon levels, knowledge of how much soil organic carbon restoration can be achieved is lacking. In addition, past research has indicated that soil organic carbon variability within a given field may be tremendous and needs to be considered when assessing soil organic carbon responses to changes in management.

Action taken: We used past studies and existing research to quantify expected soil profile changes in soil organic carbon that would likely occur under different management scenarios. In addition, we assessed the within-field variability of soil organic carbon at the Washington State University Cook Agronomy Farm at Pullman, WA.

Results: We developed probability functions of changes in soil organic carbon that would occur under different management scenarios for each agroecological zone. We found that within-field soil organic carbon was extremely variable, with differences ranging from two to three-fold, and that subsoil levels of soil organic carbon were significant and greater than topsoil levels of soil organic carbon in some locations.

Results published in:

Brown, T. T., and D. R. Huggins. 2012. Soil carbon sequestration in the dryland cropping region of the Pacific Northwest. *Journal of Soil and Water Conservation* 67(5): 406–415.

Data and Data Management

Managing and accessing diverse data generated by the REACCH project

Contributed by Paul Gessler, paulg@uidaho.edu

Issue: Large multidisciplinary projects generate diverse data to help understand patterns and answer diverse questions. Managing, archiving, and making these data and associated tools easily available as an important legacy of the research is challenging.

Action taken: We established a data management team and hired a dedicated data manager. The team developed a detailed data management plan and policy to help specify data types and timelines for making data available and accessible. The team also developed a transition plan to move REACCH data into a permanent repository to ensure continued availability beyond the funded project. The data team and Linda Urban conducted interviews and developed subsequent adoption strategies to help project scientists adjust to the new paradigm of open data sharing.

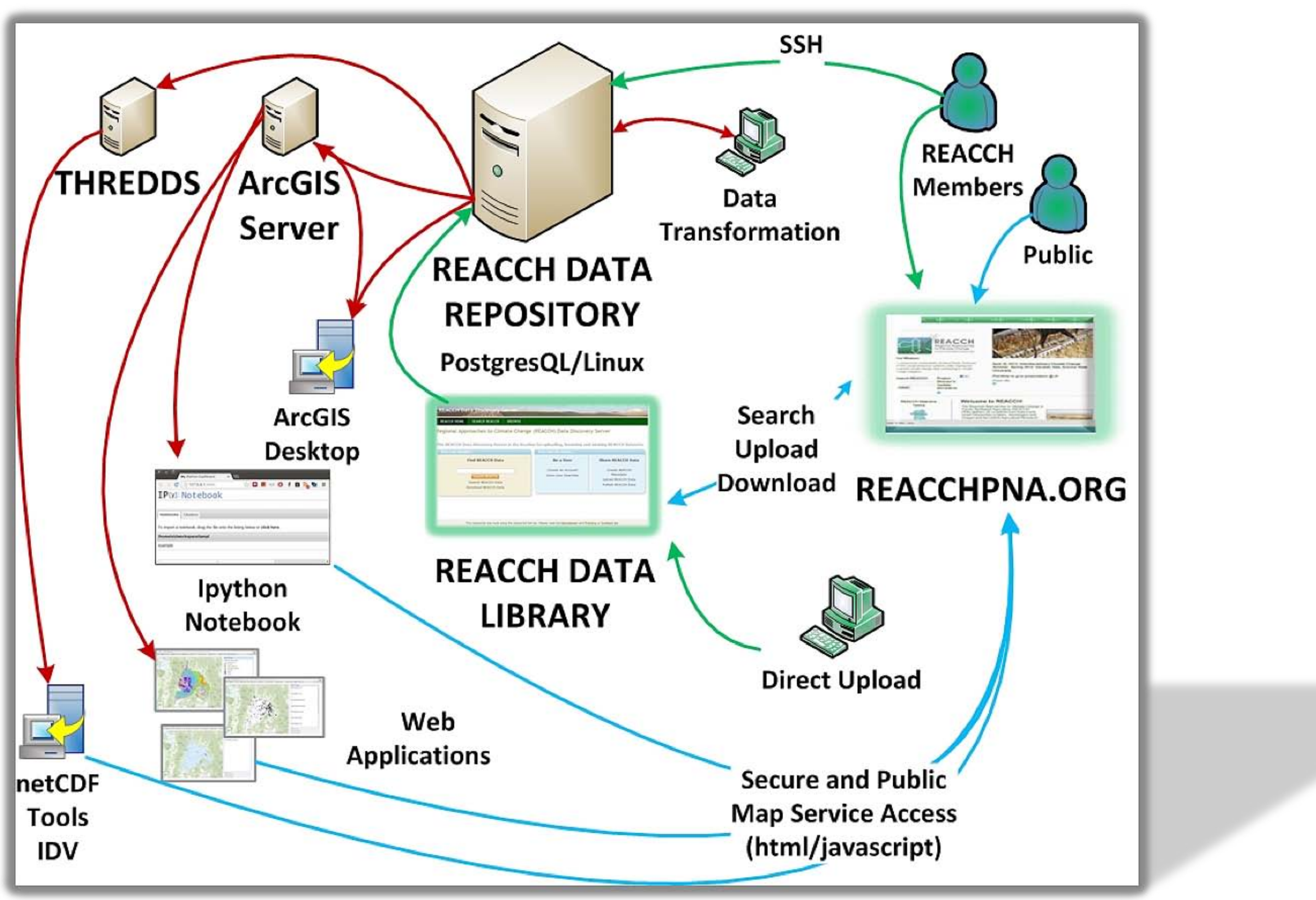
Results: The outputs include a detailed data policy, planning documents, defined flow processes, and tools to help input data into an open-source accessible data repository. Over time we modified and adapted our processes using both automated and manual methods to help researchers input data.

All data from the REACCH repository have now been transitioned and mirrored to the Northwest Knowledge Network at the University of Idaho and are openly accessible to anyone through download or by dynamic web service access. This hybridized approach for data retrieval is a model that is used by other state and federal organizations, such as NOAA, NASA, and the USDA.

A REACCH website is maintained (https://www.reacchpna.org/) with a link to data and tool output products.

Results published in:

Gessler, P. E., D. E. Seamon, and E. Flathers. Development of an open data management architecture and system to facilitate interdisciplinary research for building resilience to climate change in cereal production systems. *Frontiers in Ecology and Evolution*. In preparation.



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

Enabling REACCH data outputs to be accessible via the USDA National Agricultural Library

Contributed by Paul Gessler, paulg@uidaho.edu

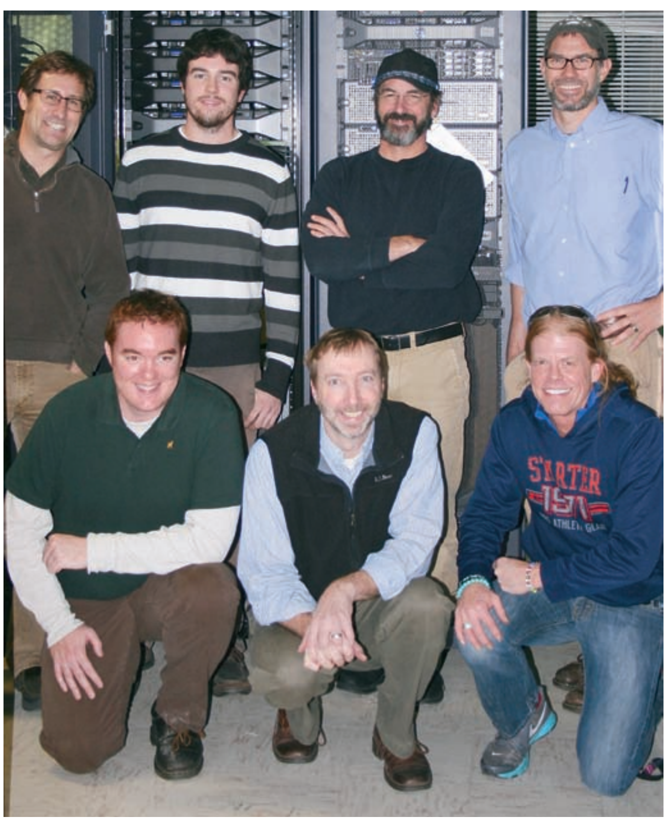
Issue: It is difficult to access data from federally funded research projects such as REACCH and share the data with the broader national and global research community. A national effort must be made to help resolve this and enable reuse of data from funded research.

Action taken: We worked with the U.S. Department of Agriculture's (USDA) National Agricultural Library AgData Commons project to implement a pilot project using REACCH data. Our teams defined data standards and types that allow REACCH data to be automatically represented on AgData Commons.

Results: We agreed upon and implemented dynamic web services to expose REACCH metadata. These web services provide automatic access through the AgData Commons national repository, making REACCH data widely accessible to researchers. The Northwest Knowledge Network at the University of Idaho is now able to repeat this process for any USDA-funded research.

Results published in:

Our REACCH web service data access can be found at https://www.reacchpna.org/data-management



Members of the REACCH cyberinfrastructure team and Northwest Knowledge Network (NKN) personnel in front of enterprise servers.

Interdisciplinary Research Framework and Legacy

Ongoing partnerships in the Pacific Northwest

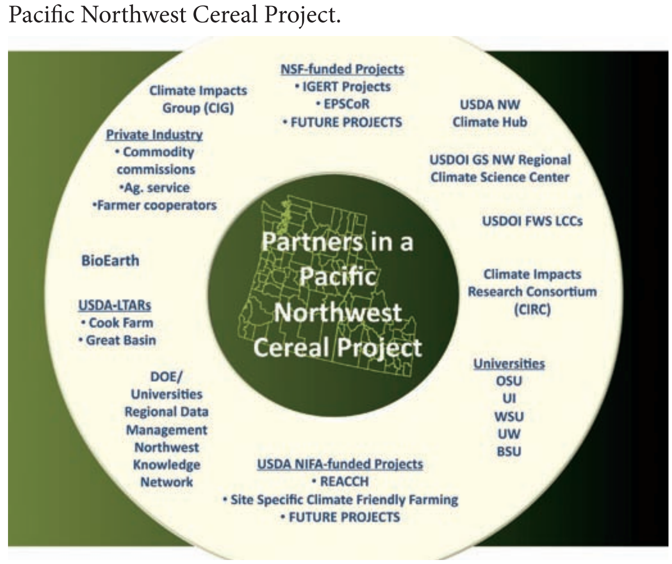
Contributed by Sanford Eigenbrode, sanforde@uidaho.edu

Issue: The challenges posed by climate change to agricultural production are ongoing and will continue long after the termination of the REACCH project. One objective of this project has been to build capacity for collaborative work to address these ongoing challenges in our region.

Action taken: We have worked to develop future research projects and to initiate and strengthen collaborative relationships with other research projects, producers, and stakeholders. Our 2015 all-project meeting included a special session for partners, with leadership from other regional projects such as BioEarth (WSU), CEREO (WSU), the newly established Long-Term Agroecosystem Research (LTAR) site (USDA, Pullman), the Northwest Climate Hub, and the Waters of the West Program (UI). Sanford Eigenbrode, REACCH Project Director, has worked as a partner and advisor to the LTAR project.

Proposals for additional research funding for multi-state and multi-institution projects have been developed by REACCH principal investigators and their collaborators. The upcoming handbook, *Advances in Sustainable Dryland Farming*, is sponsored by REACCH in collaboration with the Washington State University College of Agricultural, Human, and Natural Resource Sciences and represents a commitment to regional collaboration that addresses our production systems holistically. Producer field days cosponsored by REACCH are expected to continue annually and represent a new level of coordination in extension programming to wheat producers.

Results: Through these activities, REACCH has contributed to the development of comprehensive, multi-state, multi-agency and multi-university efforts to address agricultural challenges in a long-term, sustainable manner that reaches a broad demographic of stakeholders. Long-term efforts are summarized in the graphic shown here, which depicts the partners in an envisioned Pacific Northwest Cereal Project.



Interdisciplinary Research Framework and Legacy

Wheat initiative expert working group on wheat agronomy

Contributed by Sanford Eigenbrode, sanforde@uidaho.edu

Issue: As agriculture adjusts to changing climates while mitigating emissions of greenhouse gases, there is a pressing need to consider all the elements of production systems comprehensively. Research and interventions that consider only one or a few elements of production take the risk of failing to account for the effects of interacting biological, social, and economic components of these systems. International efforts to improve yields of pivotal crops like wheat, rice, and potatoes sometimes fall into a nonintegrated approach or emphasize genetic improvement over other factors necessary for realizing yield potentials. There is a need to raise awareness of these issues and initiate efforts to address them.

Action taken: We sponsored a workshop, "Transitioning Cereal Systems to Adapt to Climate Change," in November 2015, collocated with the Entomological Society of America and the Tri-Societies meetings in Minneapolis/St. Paul, MN.

Results: Workshop attendees recognized the importance of integrated approaches to improving and stabilizing wheat production. Sanford Eigenbrode (REACCH project director) and Bill Pan (REACCH), along with conference participant John Kirkegaard (CSIRO, Australia), worked with Brian Beres (Agriculture and Agri-Food Canada) to prepare a proposal for an Expert Working Group (EWG) on Wheat Agronomy to join the other Expert Working Groups sponsored by the International Wheat Initiative. The agronomy EWG was approved and had its inaugural meeting at Tri-Societies 2016. Its membership has grown to 40 scientists worldwide, and it was represented at the Wheat Initiative Jamboree, Dec. 6-7, 2016, in Frankfurt, Germany.

The wheat agronomy EWG is still growing. Its first effort will be to assemble a research inventory from each region of the world where wheat is grown. This process will identify gaps and opportunities for international collaboration. The effort represents an ongoing impact of REACCH on wheat production and climate change worldwide.

WHEAT INITIATIVE Coordinating global research for wheat.

The aim of the Wheat Agronomy EWG is to "bring together experts from a broad range of disciplines (vs. a silo approach) who would all contribute to the enhancement of the wheat phase as part of a systems agronomy approach that will meet the global challenges facing wheat growers and end-users today and well into the future. Emphasis will be placed on a systems agronomy approach that will enhance synergies to close the gap between genetic and on-farm yields but also meet societal goals around quality, sustainability and consistent supply considerations in the face of increasing demand and climate change." (http://www.wheatinitiative.org/activities/expert-working-groups/wheat-agronomy)

Authors meeting at the National Center of Social and Ecological Synthesis (SESYNC) during preparation of "Leading Large Transdisciplinary Projects Addressing Social-Ecological Systems: A Primer for Project Directors", June 2016.

Improving leadership for large transdisciplinary projects

Contributed by Sanford Eigenbrode, sanforde@uidaho.edu

Issue: Changing and variable climates will affect agricultural production and other coupled human and natural systems for the foreseeable future. Effective responses will require large-scale, long-term, broadly integrated, transdisciplinary projects like REACCH. Leading such projects can be challenging and requires a specialized set of skills and approaches. Future leaders can benefit from the experience and insights of current large-project directors.

Action taken: Sanford Eigenbrode (REACCH director) worked with Lois Wright Morton (Iowa State University) and Timothy Martin (University of Florida) to convene a workshop and develop a guide for future directors of large, transdisciplinary projects addressing social-ecological systems. All three collaborators were directors of large Coordinated Agricultural Projects addressing climate change (CAPs) sponsored by the U.S. Department of Agriculture's National Institute of Food and Agriculture (USDA-NIFA).

The workshop was sponsored by the National Center for Social and Ecological Synthesis and held at its headquarters in Annapolis, MD, in June 2016. The 12 participants included directors of large projects like REACCH from around the United States and in Central America. Representatives from academic institutions, USDA-NIFA, and the community of scholars studying collaboration were also included.

Results: The team developed an online resource, currently in preparation, entitled *Leading Large Transdisciplinary Projects Addressing Social-Ecological Systems: A Primer for Project Directors.* The 60-page guide includes sections on the qualities and skills of a high-functioning director, how to mold a successful team, creating a culture of collaboration, supporting the next generations of collaborative researchers, and working with stakeholders and with university administration. The primer will be hosted on the NIFA website.

Results published in:

https://nifa.usda.gov/

Methods for understanding large collaborative research projects

Contributed by David Meyer,
david.meyer.email@gmail.com

Issue: Climate change adaption and mitigation are complex issues that demand insight from a diverse group of scientists and stakeholders. While coordinated efforts across many academic disciplines and stakeholder interest areas may be the only way to address pressing societal challenges, managing these efforts requires valid and reliable measures of collaboration.

Action taken: As part of a multi-method assessment and evaluation plan, we conducted four annual surveys measuring perceptions of trust, collaboration quality, and research productivity in REACCH researchers, graduate students, and other professionals supported by the project. Items with highly variable responses across the project as well as items receiving the highest or lowest scores were highlighted and shared with project participants each year at annual, project-wide meetings. In addition, the use of summed scales and inferential statistics provided a way to make comparisons of trust, collaboration quality, and productivity across disciplines, objectives, and locations. These scores were used in combination with a social network analysis of participant collaboration to further identify areas of success and concern.

Results: The annual surveys gave participants and project leaders a way to quickly identify some areas of concern and more effectively use project-wide meeting time to create solutions. Social network graphs helped identify key collaborators within the project and provided a visualization of how objectives, disciplines, and locations were interacting. This information helped identify people, locations, disciplines, or objective areas that might need additional support.

Inclusive feedback: Making face-to-face meetings more productive

Contributed by David Meyer,
david.meyer.email@gmail.com

Issue: While some parts of large, interdisciplinary projects can work independently, many research, education, and extension opportunities demand coordination across geographically distributed groups. Good ideas and important information can come from anyone in the project, but electronically supported virtual meetings place limits on the number of people who can meaningfully participate and face-to-face meetings are resource intensive.

Action taken: We used interviews and four annual qualitative surveys of REACCH researchers, graduate students, and other professionals to understand what project management and coordination activities were needed to support the project. The online survey used open-ended questions regarding which project management and coordination activities participants deemed successful and which needed change. In addition, one question asked for other comments and suggestions that respondents wanted to share with the entire project.

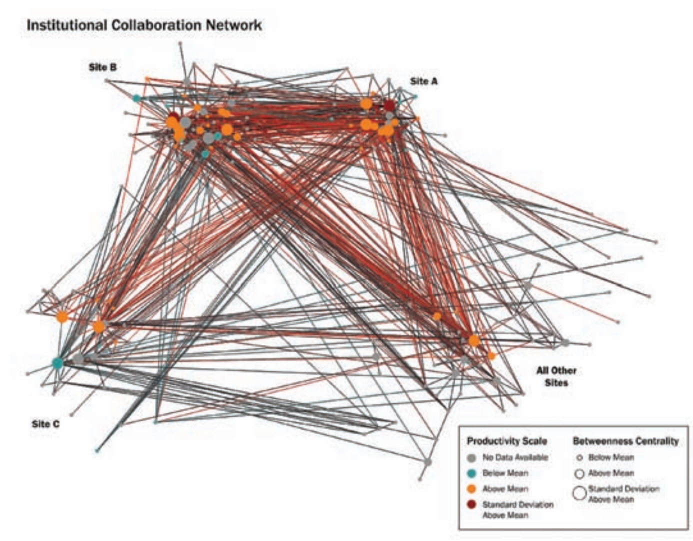
Response rates varied between 77% and 88% over the four annual surveys. To help respondents share controversial or otherwise difficult issues, respondent anonymity was protected. The results were synthesized into a report and sent back to the respondents one week before the annual meeting. At the annual meeting, these results helped define the key questions for a set of large-group dialogs and solution-finding exercises.

Results: Including everyone supported by the project and protecting respondent confidentiality helped uncover some challenging project-wide issues that could then be discussed openly, better understood, and resolved. The long-term impacts of our work include graduate students and faculty who are able to address the many the challenges of large, interdisciplinary projects by applying the tools, methods, and models we used during the REACCH project. Participating researchers will also be better able to identify and use project-wide feedback to strengthen future project proposals. We have shared the tools, methods, and models we developed and applied in the REACCH project at two professional conferences focused on team science and evaluation.

Results published in:

Meyer, D. C. 2014. A mixed-method approach to understanding team science: Working towards useful feedback. Paper presented at the Science of Team Science Conference, August 2014, Austin TX.

Meyer, D. C. 2016. Designing for multiple targets: A mixed-method approach to interdisciplinary research assessment. Paper presented at the American Evaluators Association Conference, October, 2016, Atlanta, GA.



A social network graph illustrating betweenness centrality (a measure of how an individual connects groups within an organization) and self-reported productivity across three major research sites and other geographically distributed people. Two sites have relatively high numbers of well-connected individuals and above-average productivity levels, while Site C and all other sites reported more moderate betweenness centrality and productivity scores.

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

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

Funded through Award #2011-68002-30191 from USDA National Institute of Food and Agriculture