Improving climate change mitigation and resiliency across Wisconsin's agriculture industry

Wisconsin Initiative on Climate Change Impacts
Agriculture Working Group Report
June 18, 2021

Co-chairs

Chris Kucharik, *UW-Madison Department of Agronomy and Nelson Institute for Environmental Studies*
Sara Walling, *Wisconsin Department of Agriculture, Trade, and Consumer Protection*

Participants, co-authors, and consultants

Rachel Bouressa, *Golden Sands Resource Conservation and Development Council, Inc.*
Chelsea Chandler, *Clean Wisconsin*
Jed Colquhoun, *UW-Madison Dept. of Horticulture*
Julie Dawson, *UW-Madison Dept. of Horticulture*
Sarah DeGraff, *UW-Madison Division of Extension*
Russ Groves, *UW-Madison Dept. of Entomology*
John Hendrickson, *UW-Madison Center for Integrated Agricultural Systems*
Bill Hogseth, *Wisconsin Farmers Union*
Randy Jackson, *UW-Madison Dept. of Agronomy*
Scott Laeser, *Clean Wisconsin*
Sarah Lloyd, *UW-Madison Center for Integrated Agricultural Systems*
Diane Mayerfeld, *UW-Madison Center for Integrated Agricultural Systems*
Bob Micheel, *Monroe County Land Conservation Dept.*
Michelle Miller, *UW-Madison Center for Integrated Agricultural Systems*
Paul Mitchell, *UW-Madison Dept. of Agricultural and Applied Economics*
Laura Paine, *UW-Madison Dept. of Agronomy*
Jackson Parr, *UW-Madison Division of Extension*
Jenna Pavela, *UW-Madison Dept. of Biological Systems Engineering*
Pamela Porter, *Wisconsin Department of Natural Resources*
Mark Renz, *UW-Madison Dept. of Agronomy*
Matt Ruark, *UW-Madison Dept. of Soil Science*
Gregg Sanford, *UW-Madison Dept. of Agronomy*
Gene Schriefer, *UW-Madison Division of Extension*
Kevin Shelley, *UW-Madison Division of Extension*
John Shutske, *UW-Madison Dept. of Biological Systems Engineering*
Erin Silva, *UW-Madison Dept. of Plant Pathology*

Dan Smith, *Cooperative Network*
Damon Smith, *UW-Madison Dept. of Plant Pathology*
Paul Stoy, *UW-Madison Dept. of Biological Systems Engineering*
Claire Strader, *Dane County Extension*
Jim VandenBrook, Wisconsin Greenfire
Randy Zogbaum, *UW-Madison Division of Extension*

Introduction

Improving climate change mitigation and resiliency across Wisconsin's agriculture industry

While the entire state of Wisconsin experienced a 9% decline in GHG emissions from 2005 to 2017, the agriculture sector increased by 2.3 MtCO2e (or 14.3%), which was the greatest absolute increase across all sectors, including energy production, transportation, industrial processes, and waste. As of 2017, agriculture was responsible for 15% of Wisconsin's greenhouse gas emissions (GHG). Wisconsin needs to adopt land-use and land management strategies that decrease agriculture's GHG emissions, promote soil carbon sequestration, and increase agriculture's resiliency to the climate change impacts we face. Solutions and strategies must be economically viable or incentivized for producers while providing protection from future climate change.

Soil nitrous oxide emissions resulting from nitrogen fertilizer and manure application to sustain high crop production levels account for roughly half of US agricultural greenhouse gas emissions. Annual crops and associated tillage operations also cause losses of soil organic matter in the form of carbon dioxide (CO_2) release back to the atmosphere. At the same time, a trend towards more frequent heavy rainfall events is causing increased loss of nutrients from farming systems to surface waterways and groundwater, and increased soil erosion rates that decrease soil carbon storage and crop productivity.

Four key strategies can decrease agriculture's GHG emissions and promote soil carbon sequestration:

(1) Increasing continuous living cover on agricultural land, can reduce the need for fertilizer applications and associated N2O emissions and can increase soil carbon storage. In particular, rotationally managed pasture reduces the need for grain to feed livestock (which needs large amounts of N) and stores more soil carbon than overgrazed pasture or annual cropland.

(2) Avoiding conversion of grasslands and other natural landscapes to row crop production, and avoiding conversion of agricultural land to development will prevent further loss of carbon stored in soils and trees.

(3) improving manure management to reduce liquid manure storage and better align nutrient application rates with plant nutrient need can reduce methane emissions from manure and nitrous oxide emissions from soils.

(4) Increasing nitrogen use efficiency can reduce nitrous oxide emissions from soils and reduce carbon dioxide and methane emissions from fertilizer production.

In addition to increasing soil carbon sequestration and reducing greenhouse gas emissions, all these strategies have other benefits for agriculture and society, including reducing soil erosion and runoff of agrochemicals and manure to surface waterways, reducing nitrate leaching into groundwater, increasing biodiversity across the landscape, and providing improved financial stability for producers. These changes would lead to increased resiliency of our landscapes to extreme weather events, while improving environmental conditions, human health, and agriculture's overall contribution to a changing climate.

The State of Wisconsin is a member of the US Climate Alliance, a bipartisan coalition of states committed to upholding the objectives of the 2015 Paris Accord. The US Climate Alliance has adopted the greenhouse gas emission reduction goal of at least 50-52% below 2005 levels by 2030 and net zero emissions as soon as practicable and no later than 2050. The aforementioned agricultural land management changes, and other improved efficiencies in farm energy use, have the potential to reduce the Wisconsin's agricultural GHG emissions and increase soil carbon storage. They also have the potential to provide cross-cutting benefits and other ecosystem services due to their implementation, which can help agriculture adapt to a changing climate.

This report presents a review of climate change impacts to various sectors of Wisconsin agriculture, including animals, specialty and grain crops, grazing systems, and the agricultural and food supply chain. The diversity of agriculture across Wisconsin from southern landscapes dominated by corn, soybeans, and alfalfa, to regions in the central and north supporting potato and vegetable production, cranberry, and other fruit crops, means that climate change will have a variety of impacts depending on when (e.g. at what time of the year) those changes occur. For example, increased warming in the spring and fall can extend the growing season for summer crops like corn, beans, and alfalfa, but warming in summer could push temperatures outside the optimal range for some crops like potato. Increased temperatures also accelerate the rate of phenological development of plants, and therefore adoption of new varieties that are able to take advantage of increased warmth is an important adaptive strategy.

Increased temperatures during the winter can reduce the formation of ice and chilling units that cranberries need, and more pests may overwinter and new pests may appear as winters become less severe across Wisconsin. Increasing temperatures during summer can lead to increased irrigation demands by crops, especially those found in the Central Sands region that supports diverse potato and vegetable production. Farmers in other regions may begin to look towards irrigation as another adaptive strategy to deal with more heat and increased frequency of droughts during summers. More summer heat stress on livestock and in particular dairy cows could lead to lower milk production. Increased precipitation could lead to more runoff, flooding events, and fields with elevated groundwater tables that cause more management challenges. Increased frequency of extreme events – in particular heavy rainfall – will continue to cause increased challenges to managing soils and agrochemicals. Climate change will also impact workers, people, and communities associated with agriculture. Therefore, the anticipated response of Wisconsin agriculture to changing climate, atmospheric composition, and land management contains a wide range of uncertainty and potential impacts dependent on region and the crops that are being grown.

Table of Contents

Section I:

Greenhouse Gas Emissions and Mitigation:

How can agriculture reduce its contributions to changing climate?

1A: Greenhouse gas emissions from Wisconsin Agriculture

Author: Chris Kucharik

Key Source and reference for this section: Wisconsin Department of Natural Resources, 2020. *Wisconsin Greenhouse Gas Emissions Inventory Report*. Publication number AM-580-2020. 14pp.

Overall, Wisconsin greenhouse gas (GHG) emissions decreased by about 9% between 2005 to 2017, and comprised 1.8% of total US emissions in 2017, but agriculture increased the most (absolute increase) among all Wisconsin sectors by 2.3 MtCO2e during the study period (WI-DNR, 2020) (see Table 1A.1 and Figure 1A.1 below). The Wisconsin agriculture sector estimates include nitrous oxide (N_2O) emissions – mainly from fertilizer use, carbon dioxide (CO_2) released from soil management as well as plant residue burning, and methane (CH_4) emissions that largely originate from enteric fermentation and manure. Carbon dioxide accounts for the largest share of Wisconsin GHG emissions in 2017 at 81.3%, methane at 9.7%, and nitrous oxide 6.7% (WI-DNR 2020).

	2005	2017	Change	
			Amount	Percent
	MtCO2e			
Energy	*111.8*	*98.8*	*-13.0*	*-11.6%*
Electricity Generation	48.3	40.5	-7.8	-16.1%
Residential	10.2	9.1	-1.1	-10.8%
Commercial	6.2	6.1	-0.1	-1.6%
Industrial	15.8	13.7	-2.1	-13.3%
Transportation	31.3	29.4	-1.9	-6.1%
Industrial Processes	3.4	4.0	+0.6	+17.6%
Agriculture	16.1	18.4	+2.3	+14.3%
Waste	2.5	1.0	-1.5	-60.0%
Total - All Sectors	**133.9**	**122.2**	**-11.6**	**-8.7%**

Table 1A.1. Changes in Wisconsin emissions by economic sector from 2005 to 2017. Source: Wisconsin Department of Natural Resources, 2020. *Wisconsin Greenhouse Gas Emissions Inventory Report*. Publication number AM-580-2020. 14pp.

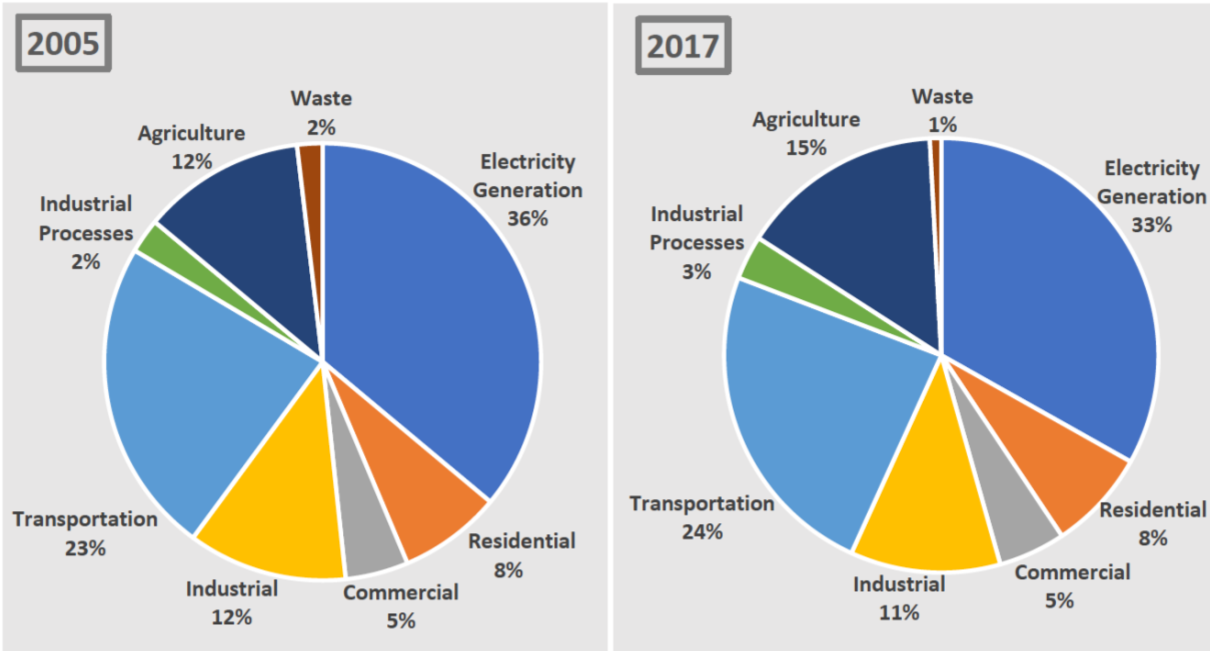


Figure 1A.1. Wisconsin emissions by sector in 2005 compared to 2017. Source: Wisconsin Department of Natural Resources, 2020. *Wisconsin Greenhouse Gas Emissions Inventory Report*. Publication number AM-580-2020. 14pp.

Agricultural related GHG emissions increased from 16.1 MtCO2e in 2005 to 18.4 MtCO2e in 2017, an increase of 14.3%. The only other Wisconsin sector to see an increase during that time period was industrial processes (+0.6 MtCO2e) (WI-DNR 2020). Agriculture represented 12% of total state GHG emissions in 2005, and 15.1% in 2017 (WI-DNR 2020). Agriculture represents the largest fraction of Wisconsin's methane emissions, and most of the N_2O emissions also originate with agricultural activity. While agriculture is a source of greenhouse gas emissions, Wisconsin's forests were a net sink of carbon in 2017, removing an estimated 40.4 MtCO2e from the atmosphere. However, this amount was a reduction of 25.9% from values estimated for 2005 (-54.5 MtCO2e) (WI-DNR 2020). While Wisconsin's natural landscape continues to accumulate carbon on an annual basis, the rate of accumulation declined during the 2005 to 2017 time period.

In summary, although Wisconsin made significant progress in reducing GHG emissions (-9%) from 2005 to 2017, the agricultural sector experienced a significant increase and now comprises 15% of Wisconsin's total GHG emissions. The large majority of methane and nitrous oxide emissions in Wisconsin are associated with agricultural activity, including use of synthetic nitrogen fertilizer, enteric fermentation, and manure. Therefore, finding ways to reduce GHG emissions in the agricultural sector are key to supporting a continued downward trend in the state's GHG emissions and contribution to a changing climate. Several recommendations for reducing GHG emissions from Wisconsin agriculture are presented in this report.

1B: Increase continuous living cover

Authors: Gregg Sanford and Randy Jackson

Keeping agricultural fields green year-round to benefit Wisconsin agriculture and environmental health

Warmer winters, wetter springs, and more extreme rainfall events have created economic and management hardships for Wisconsin farmers in recent years. Waterlogged soils delay planting in the spring and harvesting in the fall. Extreme heat reduces milk production and increases water usage. These wetter conditions also impair water quality because of more nutrient and soil loss from cropped fields. Other WICCI working groups mention these water quality problems and include the need to address agricultural runoff in their priorities.

> **Environmental/Social Justice**
>
> Healthy soils benefit communities and producers by helping to slow runoff, regulate greenhouse gases, infiltrate water, and retain nutrients. Promoting perennial vegetation will also help mitigate flooding and prevent water pollution that can be particularly difficult for low-income communities

Today there is a move in agriculture toward keeping fields green year round. The change in land-use over the last 200 years across a large portion of Wisconsin from tallgrass prairie and oak savanna to row-crop agriculture has led to higher yields but also increased greenhouse gas emissions, decreased soil health, and increased agrochemicals in our surface and drinking water. The trend toward concentrated animal feeding operations (CAFOs) has driven a reliance on feeding grain to livestock and a loss of perennial pastures. Tillage practices for row-crops degraded soil health, including the ability of agricultural soils to store carbon. This decline in soil health has led to higher rates of inorganic nutrient fertilizer and liquid manure applications to sustain crop productivity levels.

To make Wisconsin's agricultural system more resilient to climate change, we need continuous living cover systems that improve soil health by building soil aggregation, biodiversity, and organic matter. The best approach to this is increasing perennial pastures that are grazed and/or hayed to feed livestock. The next most likely approach is increasing cover of the perennial crop alfalfa, which provides significant soil protection of extant soil resources. Finally, when annual crops are used, incorporating cover crops can slow erosion and degradation of soils.

The more livestock are grazed on perennial pastures and cover crops, the less grain is needed for animal feed, which will reduce loss of soil to erosion, carbon and nutrients as greenhouse gases, nutrients to runoff and leaching, and biodiversity overall. For more background these issues, please visit the Agriculture Working Group on the WICCI webpage.

1C. Avoid conversion of grasslands and other natural landscapes

Authors: Chris Kucharik and Sara Walling

Soil health is directly related to the amount of soil carbon (organic matter) contained. Previous land-use change across a large portion of Wisconsin – from tallgrass prairie and oak savanna/grassland – to row crop agriculture over the last 200 years contributed to a 30-60% loss in soil carbon back to the atmosphere (Kucharik et al. 2001; Kucharik and Brye 2003). Also, increased use of tillage in traditional row crop production systems further diminished the ability of agricultural soils to store carbon. Therefore, land use conversion from natural systems to managed ones have led to increased GHG gas emissions as well as increased agrochemicals in our surface and drinking water.

We also know that deliberate rehabilitation of agricultural land with native prairie and grassland vegetation either as part of private efforts or the federal Conservation Reserve Program (CRP), which began in 1986, can enhance soil C accumulation (Brye and Kucharik, 2003; Kucharik et al. 2003; Kucharik 2007). Sequestered C via land restoration efforts in degraded agricultural soils is attributable to a higher allocation of carbon obtained by photosynthesis photosynthate belowground to a dense, fibrous root system, a reduction in organic matter decomposition rates, the cessation of plowing and tillage, and a reduction in wind and water erosion (Kucharik 2007).

Therefore, we need to avoid grassland and/or natural vegetation conversion to row crop production or development. By increasing perennial vegetation on the landscape, we will move towards increasing soil C sequestration, reducing soil erosion, runoff, and nitrate leaching into groundwater, and increase biodiversity across the landscape. These changes would lead to increased resiliency of our landscapes to extreme weather events, while improving environmental conditions, human health, and agriculture's overall contribution to a changing climate.

References

Kucharik, C.J. (2007). Impact of Prairie age and soil order on carbon and nitrogen sequestration. The Soil Science Society of America Journal, 71 430-441.

Kucharik, C.J., J.A. Roth, and R.T. Nabielski (2003). Statistical assessment of a paired-site approach for verification of C and N sequestration on Wisconsin Conservation Reserve Program (CRP) land. Journal of Soil and Water Conservation 58, 58-67.

Kucharik, C.J., K.R. Brye, J.M. Norman, J.A. Foley, S.T. Gower, and L.G. Bundy (2001). Measurements and modeling of carbon and nitrogen cycling in agroecosystems of southern Wisconsin: Potential for SOC sequestration during the next 50 years. Ecosystems 4, 237-258.

1D: Improve manure management

Authors: Kevin Shelley and Sara Walling

Manure excreted from dairy and beef cattle, represents the second largest source of greenhouse gas emissions on most Wisconsin livestock farms behind the methane emitted directly by cattle from enteric fermentation. During the processes of collecting manure from livestock handling and confinement facilities and, particularly, after manure is applied to the soil in crop production fields, significant amounts of nitrous oxide (N_2O), carbon dioxide (CO_2) and ammonia (NH_3, a potential GHG when transformed to N_2O), can be emitted. The largest source of greenhouse gasses associated with manure management among Wisconsin dairy farms is methane (CH_3) from liquid manure in storage. Anaerobic methane producing bacteria thrive when liquid manure is stored for several months in lagoons, pits or tanks. Because of this, and because storage systems offer opportunity for consistently applicable solutions, efforts to mitigate GHG's from manure should focus on liquid manure in storage structures.[1]

Options:

Manure processing practices such as liquid-solid separation and sand separation can reduce methane production by separating the organic solids from the liquid portion, reducing activity by methanogenic microbes. Even more effective would be covering liquid manure storage structures with impermeable caps and burning (flaming) the methane gas as it is vented (released). This converts the methane to carbon dioxide which has less global warming potential. A common practice in some other countries, this approach is not common in the U.S.

Processing manure in an anaerobic digestion system has the potential to reduce methane by as much 50 percent, as well as eliminating N_2O otherwise produced at the manure pit surface (aerobic-anaerobic interface).[1] Methane captured in manure digesters can be used as a fuel source for electricity generators for on-farm use or to be sold to the local electric utility and sourced into the distribution grid. This further reduces greenhouse gasses as it displaces energy otherwise produced with fossil fuel sources. Manure digesters have been constructed on a number of larger dairies in Wisconsin, often in partnership with third-party entities.

However, electric power purchasing rates offered by utilities have often been inadequate to make these co-generation investments feasible. Recently, farms with existing digesters have found new market potential for their methane as compressed natural gas (CNG) for sale as transportation fuel. Pursuing strategies to design anaerobic manure digesters and develop markets for farm-produced biogas to provide greater economic feasibility on a diversity of livestock farm sizes and types would provide significant opportunity for agricultural greenhouse gas reduction from Wisconsin farms.

Other strategies to minimize GHG emissions from both liquid and solid manure types are limited and produce tradeoffs. Nitrous oxide and ammonia are produced under aerobic conditions. Generally, minimizing the amount of time that excreted manure is present in barns or feedlots will reduce production of nitrous oxide and ammonia. Timely collection and land application to dry soil are advised. Wet and warm soil conditions are favorable for microbial conversion of organic N to N_2O. Manure applications to the soil surface, if not incorporated or injected within 72 hours, can result in as much as 30% of the N content being lost to ammonia volatilization.[2] Injecting manure or incorporating beneath the soil surface with tillage can prevent ammonia volatilization, but will often result in some N_2O production and atmospheric emission.

Therefore, best management practices for solid and semi-solid manure, from a GHG mitigation standpoint, include timely manure collection and land application, with incorporation, when soil moisture is low. Unfortunately, these practices may, at times, conflict with BMP's for soil conservation and local water resource protection. In all cases, manure application rates should not exceed expected crop needs for the amount of nitrogen required by the current or following crop.

Manure composting and managed grazing are associated with tradeoffs in GHG emissions as well. Composting is normally associated with N_2O and NH_3 release as the manure solids aerobically decompose. The compost produced, however, is a more innocuous humic form of organic material and nutrients and affords greater flexibility for application to cropland.[3] With grazing, N_2O is produced in the highly concentrated areas where urine is excreted to soil. However, perennial pastures managed for high productivity with intensive rotational techniques can sequester and store atmospheric carbon at potentially higher levels than annual cropping systems.[4] Manure composting, as a manure management system, and managed grazing, as a livestock production system, both offer opportunity for reducing agricultural contributions to GHG's. More research and education in these areas is likely needed to realize those opportunities.

References

[1.] Aguirre-Villegas, Horacio A. 2017. Greenhouse Gas and Ammonia Emissions from Dairy Manure Management Systems. UWEX A4131. Sustainable Dairy Factsheet Series. http://www.sustainabledairy.org/Documents/DairyCap_GreenhouseGas_FactSheet_Final2.pdf.

[2.] Laboski, Carrie A.M. and Larry Bundy, 2012. Nutrient application guidelines for field, vegetable and fruit crops in Wisconsin. UWEX A2809, https://soilsextension.webhosting.cals.wisc.edu/wp-content/uploads/sites/68/2014/02/A2809.pdf.

[3.] Bai, M., Flesch, T., Trouve, R., et al. 2020. Gas emissions during cattle manure composting and stockpiling. Journal of Environmental Quality 2020:49:228-235. https://doi.org/10.1002/jeq2.20029.

[4.] Sanford, Gregg R., et. al., 2021. Perenniality and diversity drive output stability and resilience in a 26-year cropping systems experiment. Field Crops Research. Volume 263, 1 April 2021, 108071.

1E: Increase nitrogen use efficiency

Author: Chris Kucharik

The use of inorganic nitrogen fertilizers to support crop growth increases the amount of N that is returned to the atmosphere as the greenhouse gas known as nitrous oxide (N_2O). On a mass basis, nitrous oxide is 300 times more potent than carbon dioxide (CO_2) as a greenhouse gas. Therefore, increasing nitrogen use efficiency (NUE) – or simply reducing the amount of N fertilizer applied – can have an immediate and direct effect on mitigating agriculture's contribution to climate change. Currently, crops that require a high amount of N fertilizer like corn are only able to recover approximately 50% of the amount that is applied. The remainder is lost through leaching to groundwater, runoff to surface waterways, and N_2O emissions.

Some of the most important ways to increase efficiencies are to ensure that over-application of N fertilizer does not occur (e.g. follow extension guidelines and recommendations in *A2809-Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin* for the correct crop). Consider split applications of the correct amounts, modify the timing of application to minimize the risk of loss due to extreme weather (e.g. heavy rainfall), decide on where best to apply fertilizer where it will have the most benefit to crops, and is at lowest risk to enter waterways.

References

Laboski, C.A.M. and J. B. Peters. 2012. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. University of Wisconsin Extension Publication A2809, 92pp.

1F: Wisconsin Agriculture's Role in achieving GHG emission reductions

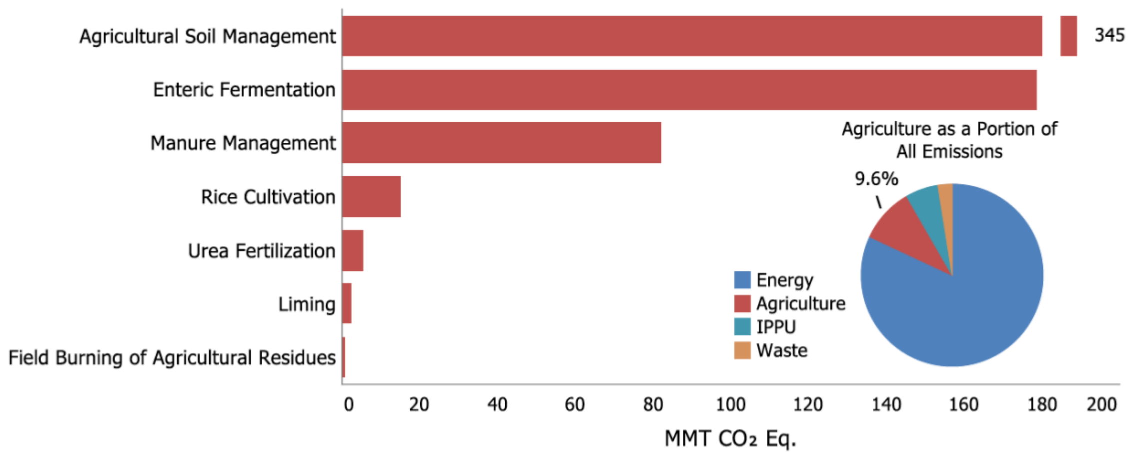
Authors: Jim VandenBrook, Chelsea Chandler, Diane Mayerfeld, Chris Kucharik, Sara Walling, Pam Porter

The State of Wisconsin is a member of the US Climate Alliance, a bipartisan coalition of states committed to upholding the objectives of the 2015 Paris Accord. The US Climate Alliance has adopted the greenhouse gas emission reduction goal of at least 50-52% below 2005 levels by 2030 and collectively achieve net zero emissions as soon as practicable and no later than 2050 (see http://www.usclimatealliance.org).

These are ambitious goals. In Wisconsin, agriculture is a significant source of greenhouse gases accounting for 15.0% of the state's emissions, which is higher than the U.S. average of 9.6% in 2019 (see Figure 5-1 below). And while greenhouse gas (GHG) emissions in the Wisconsin have decreased by approximately nine percent between 2005 and 2017, agriculture emissions increased by 2.3 $MtCO_2e$ during the same time period, more than any other sector in the state, but is reflective of longer-term changes in the U.S. agriculture.

For a broader perspective, a recent annual report from the US Environmental Protection Agency shows the sources of GHG emissions from U.S. agriculture and how those have changed from 1990-2019. From 1990 to 2019, CO_2 and CH_4 emissions from U.S. agricultural activities increased by 9.9% and 17.5%, respectively, and nitrous oxide emissions increased by 10.4%. Figure 5-1 taken from the U.S. EPA report illustrates the major sources of U.S. agricultural GHG emissions in 2019.

Figure 5-1: 2019 Agriculture Chapter Greenhouse Gas Emission Sources



In 2019, the Agriculture sector was responsible for emissions of 628.6 MMT CO_2 Eq.,[1] or 9.6 percent of total U.S. greenhouse gas emissions. Methane emissions from enteric fermentation and manure management represent 27.1 percent and 9.5 percent of total CH_4 emissions from anthropogenic activities, respectively. Of all domestic animal types, beef and dairy cattle were the largest emitters of CH_4. Rice cultivation and field burning of agricultural residues were minor sources of CH_4. Emissions of N_2O by agricultural soil management through activities such as fertilizer application and other agricultural practices that increased nitrogen availability in the soil was the largest source of U.S. N_2O emissions, accounting for 75.4 percent. Manure management and field burning

The agricultural sector can influence the carbon cycle on both sides of the equation: by increasing carbon storage in *sinks* and by decreasing *sources* of emissions. Agricultural management can help reduce emissions from the sector, and can remove some CO_2 from the atmosphere and store it in soils. For example, consider the following areas where significant changes in agriculture can have a large impact on GHG emissions.

1. **Manure management and energy production.** Methane and nitrous oxide emissions from manure account for roughly 12% of agricultural greenhouse gas emissions in the US, and more in Wisconsin with its many dairy farms. Manure emissions from dairy cows increased 90% from 1990 to 2019. Anaerobic digestion can nearly eliminate methane emissions from stored manure, and the captured methane can replace fossil fuels for electricity generation, heating, or transportation, further reducing total greenhouse gas emissions (U.S. Environmental Protection Agency 2020; Aguirre-Villegas et al. 2015).

2. **Nitrogen fertilizer management.** Production of nitrogen fertilizer is energy-intensive and results in significant CO_2 and methane emissions. Even more significantly, less than half of nitrogen applied to agricultural fields is taken up by crops, and some of the remainder may be converted to nitrous oxide, a potent greenhouse gas, or may contaminate surface and groundwater. Nitrous oxide emissions from soils account for more than half of agriculture's total greenhouse gas emissions in the US.

3. **Soil management.** Soils in natural ecosystems tend to store carbon, but regular soil disturbance in agricultural systems can result in loss of soil carbon to the atmosphere. Management practices that limit soil disturbance and maximize year-round plant cover and living roots promote carbon storage, improve soil health, and reduce erosion and water pollution risks. Some practices, such as reduced tillage or use of cover crops, can be implemented on most cropland without major changes to the farming system, but only reduce carbon losses slightly; other practices, such as converting annual cropland to well-managed diverse pasture or silvopasture, can store much more carbon per acre but require greater changes to the farming system.

   How much carbon can be removed from the atmosphere with each of these practices varies significantly depending on soil type, management details, and climate. Much of the research on carbon stored by best management practices sampled only the upper 10 to 30cm of the soil; other research indicates that soil carbon can be in flux at least up to depths of 1 meter (Kaye and Quemada 2017; Dignac et al. 2017; Sanford et al. 2012). Figure 4 below provides a visual estimate of the carbon storage potential of selected practices.

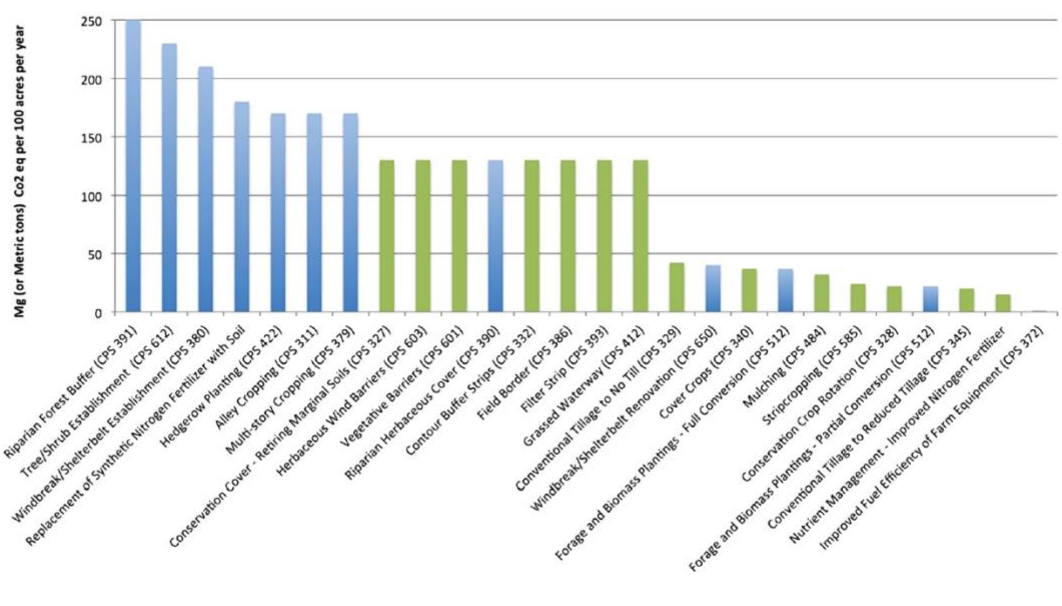


Figure 4. Soil Carbon Sequestration/Emissions Reduction Potential by Management Practice
Source: NRCS COMET-Planner (as excerpted from Biardeau et al., (2016).)

The green bars indicate practices designated by NRCS as “soil health building blocks”; the blue bars are practices designated by NRCS as advancing other environmental goals such as water quality protection.

4. **Farm energy consumption and efficiency.** Farms also have many opportunities to integrate energy efficiency measures into their buildings, vehicles, and operations. From upgrading to LED lighting to tuning up grain dryers, using efficient appliances and equipment helps reduce energy use – and costs and greenhouse gas emissions too. More options are emerging for zero-emission trucks, tractors, and other equipment as well. While energy efficiency and renewable energy upgrades pay for themselves over time, a variety of programs exist to reduce and help with upfront costs such as rebates through the statewide Focus on Energy program, Property Assessed Clean Energy (PACE) financing, low-interest loans, and solar group buy programs. Payback periods for on-farm renewable energy installations will vary based on a variety of factors, including utility territory and electricity buyback rates for selling excess energy to the grid.

The path forward and recommendations

USDA is coming up with a strategy for climate-smart agriculture as part of a whole-of-government effort to address climate change. A number of cropland, soil, and herd management strategies for agriculture outlined in the WICCI Agriculture Working Group report are "*climate smart*" and have the potential to significantly reduce the state's agricultural emissions and achieve a 50% reduction (from 2005 levels) by 2030. They also have the potential to provide cross-cutting benefits or other ecosystem services due to their implementation (see Table 1 below). These recommended agricultural practices include:

- Full implementation of state nutrient management standards (at a minimum) to better align nutrient application rates with plant nutrient need and reduce nitrous oxide emissions by limiting over-application of manure and nitrogen fertilizer to croplands.
- Increase the amount of perennial grasses and cover crops to establish continuous living cover on agricultural land to avoid losses of soil nitrogen and phosphorus and expand long-term sequestration of soil carbon.
- Increase amount of rotational grazing (e.g. managed grazing and grass-based production, heifer pasturing) in livestock and cropping systems management to reduce amount of grain needed for animal feed and increase soil carbon
- Increase the use of no-tillage in crop management to decrease soil erosion and increase likelihood for soil carbon sequestration
- Improved diet for dairy animals to reduce methane production
- Flaring of methane from stored manure to decrease emissions
- Support deployment of manure digestion and biogas systems

The Governor's Task Force on Climate Change report recognized several of the aforementioned ideas and came up with an expanded list of four key agricultural strategies to help Wisconsin better adapt to and mitigate climate change, while seeking new economic opportunities in renewable energy and conservation.

- Support farmer-led watershed groups
- Pay farmers to increase carbon storage in agricultural working lands
- Avoid conversion of natural working lands
- Make managed grazing livestock production systems an agricultural priority

Unfortunately, there are few practical tools (see USDA Comet-Farm) to help farmers evaluate the impact of implementing the strategies discussed here, either individually or combined, especially as it relates to emission reduction goals. Furthermore, there are even fewer, if any approaches that are aimed at larger landscape scales, like watersheds, counties, or regions that would have more relevance to policy-decision making. Identifying "climate smart" tools – that are more tailored to Wisconsin's diverse agricultural industry – and that can quantify GHG reductions is an important next step to strengthen Wisconsin farmers ability to adapt to a changing climate and increase agroecosystem and economic resilience. We also suggest that future policy decision-making considers food-energy-water systems as integrated entities, and not develop policy in separate silos that leads to unintended, but predictable consequences, to ecosystems, the environment, and farmer and community livelihoods.

Table 1F.1. Other cross-cutting benefits associated with some agricultural management practices recommended for expansion across Wisconsin.

Practice and benefits	GHG/Climate change	Water Quality	Soil Health	Biodiversity	Climate resilience	Economics
Continuous living cover, including: **- pasture (rotationally grazed),** **- silvopasture (planted),** **- cover crops**	increased soil C, reduced emissions from reduced fertilizer production/use	Increased uptake of residual soil nitrogen reduces nitrate leaching to groundwater; reduced soil erosion and runoff; increased infiltration	Increased overall soil quality and soil structure; reduced soil erosion, increased organic carbon, nutrient recycling and N fixation, reduced compaction	Increased soil microbes and wildlife including birds, mammals, arthropods, pollinators	Improved soil erosion resistance to heavy rain and wetter weather	improved yields, lower N application in following year; reduced need for herbicides and pesticides; reduced damage by disease and insects; potential future markets that may pay for carbon credits and other ecosystems services
No-till crop management	Improved potential for increased soil C sequestration; reduced CO2 emissions from equipment and fuel usage	Increased water infiltration, reduced surface runoff, erosion, and loss of nutrients to surface water ways and groundwater	Improved soil quality and soil structure; reduced compaction of soil; improved water holding capacity	Increased soil biological activity	Increased soil erosion resistance to extreme rainfall events and increased precipitation; conservation of soil moisture in drought conditions	Reduce fuel usage, labor, and time spent in tractor; potential future markets that may pay for carbon credits
Maintain or restore prairie, forest, and other natural habitats	Increased soil carbon storage and reduced GHG emissions like nitrous oxide	Increased water infiltration, reduced surface runoff, erosion, and loss of nutrients to surface water ways and groundwater	Increased overall soil quality and soil structure; reduced soil erosion, increased organic carbon, nutrient recycling and N fixation, reduced compaction	Increased soil microbes and diversity; increased vegetative species diversity; increased wildlife including birds, mammals, arthropods, pollinators	Increased soil erosion resistance to extreme rainfall events and increased precipitation; conservation of soil moisture in drought conditions	Income from conservation programs like CRP; potential future markets that may pay for carbon credits and other ecosystems services

Identifying farmer supporting scenarios and quantifying their impacts will require workgroups to analyze the existing literature on the emission reduction potential of the proposed management strategies, and evaluate several implementation scenarios within Wisconsin agriculture and quantify the magnitude of GHG reductions that could be achieved with recommended practices. It should also be noted that implementing more widespread land management practices such as rotational grazing and pastureland, cover crops, no-tillage or conservation tillage, and prairie restoration have a wide range of other environmental and economic benefits (or ecosystem services).

Section II: Climate Impacts

Direct impacts of climate change on Wisconsin agriculture and ideas for adaptation

2A. Overview of relationship between climate change and agriculture

Author: Chris Kucharik

The diversity of agriculture across Wisconsin from southern landscapes being dominated by corn, soybeans, and alfalfa, to regions in the central and north supporting potato and vegetable production, cranberry, and other fruit crops, means that climate change will have a variety of impacts depending on when (e.g. at what time of the year) those changes occur. For example, increased warming in the spring and fall can extend the growing season for summer crops like corn, beans, and alfalfa, but warming during the core of the growing season could push temperatures outside the optimal range for some crops like potato. Increased temperatures also accelerate the rate of phenological development of plants, and therefore adaptation to new varieties that are able to take advantage of increased warmth is an important adaptive strategy.

Increased temperatures during the winter can reduce the formation of ice and chilling units that cranberries need, and pests may overwinter easier and new pests may appear as they push north from southern states as winters become less severe across Wisconsin. Increasing temperatures during summer can lead to the need for irrigation demands (or more irrigation demands) by crops, especially those found in the Central Sands region that supports diverse potato and vegetable production. Farmers in other regions may begin to look towards irrigation as another adaptive strategy to deal with more heat and increased frequency of droughts during summers. More summer heat stress on livestock and in particular dairy cows could lead to lower milk production. Increased precipitation could lead to more runoff, flooding events, and fields with elevated groundwater tables that cause more management challenges. Increased frequency of extreme events – in particular heavy rainfall – will continue to cause increased challenges to managing soils and agrochemicals.

Therefore, the anticipated response of Wisconsin agriculture to changing climate, atmospheric composition, and land management contains a wide range of uncertainty and potential impacts dependent on region and crop type. The tables below review the range of positive, negative, and indirect impacts that climate change could have on Wisconsin agriculture. More specific examples are given in other sections in this report.

Table 2A.1: Positive Impacts on Agriculture

Evidence of Climate Change	Impact on Agricultural Production
Longer frost free periods	Use of higher yielding genetics; increased growing period for grasses

Lower daily maximum temperatures in summer	Reduced plant stress, demand for water
More freeze/thaw cycles in winter	Increased soil tilth and water infiltration
More summer precipitation	Reduced plant stress
More soil moisture	Reduced plant stress
Higher dew point temperatures	Reduced moisture stress
Warming temperatures	Increased growing degree days
More diffuse light (increased cloudiness)	Reduced plant stress
Higher water use efficiency (increased CO_2)	Higher productivity
Warmer spring soil temperatures	Earlier planting, use of higher yielding genetics
Reduced risk of late spring or early fall frosts	Use of higher yielding genetics
Increased atmospheric CO_2 levels	Increased photosynthesis, biomass, yields for C3 plants

Table 1A.2: Negative Impacts on Agriculture

Evidence of Climate Change	Impact on Agricultural Production
More spring precipitation causes water logging of soils	Delay planting, reduced yields, compaction, change to lower yielding genetics, and increase in soilborne plant pathogen issues
Higher humidity promotes fungal diseases	Yield loss, increased remediation costs
Higher nighttime temperatures in summer	Plant stress & yield loss
More intense rain events at beginning of crop cycle	Re-planting and field maintenance costs; loss of soil productivity and soil carbon
More droughts	Yield loss; stress on livestock; increase in irrigation costs; increased costs to bring feed and water to livestock

More floods	Re-planting costs, loss of soil productivity and soil carbon; damage to transportation infrastructure may reduce delivery to milk processing plants
More over-wintering of pests due to warmer winter low temperatures	Yield loss, increased remediation costs
More vigorous weed growth due to temperature, precipitation and CO_2 changes	Yield loss, increased remediation costs
Summertime heat stress on livestock	Productivity loss, increase in miscarriages, may restrict cows on pasture
Temperature changes increase disease among pollinators	Losses to cropping (forage, fruits, vegetables) systems
Increased taxes or regulations on energy-dependent inputs to agriculture (e.g., nitrogen fertilizer)	Profitability impacts on producers; loss of small-scale farm supply dealers
New diseases or the re-emergence of diseases that had been eradicated or under control	Enlarged spread pattern, diffusion range, and amplification of animal diseases

Table 2A.3: Indirect Impacts of Associated Climate Change on Agriculture

Situational Change	Impact on Wisconsin Agriculture
Regulation involving greenhouse gas emissions	Potential increased costs to meet new regulations; opportunities to participate in new carbon markets and increase profits
Litigation from damages due to extreme events or management of carbon markets	Legal costs may increase
New weed and pest species moving into Wisconsin	Control strategies will have to be developed; increased pest management costs as well as crop losses

Vigorous weed growth results in increased herbicide use	Increase in resistance or reduction in time to development of resistance; regulatory compliance costs or litigation over off-site damages from pesticides
Possibility of increased inter-annual variability of weather patterns	Increased risk in crop rotation, genetic selection, and marketing decisions
Increased global demand for food production due to climate and demographic changes	New markets; increase in intensification of production; increase in absentee ownership
Increased period for forage production	Decreased need to large forage storage across winter for livestock operations

2A.1 Growing season length and growing degree days (GDD)

Author: Chris Kucharik

Wisconsin is situated in the Upper Midwest region and has a significant north-south gradient in annual mean temperature and an accompanying west-east gradient in rainfall. This has contributed to the historical differences in native vegetation that dominated the south and west prairie / oak savannah ecotone from the northern and eastern forest ecotone in Wisconsin. Correspondingly, the climate gradient in Wisconsin leads to significant differences in growing season length and the number of growing degree days (GDDs) available for plant growth.

Climate change has already caused a significant lengthening of the growing season, particularly in the central and northern portions of the state (Kucharik et al. 2010), and that trend is likely to continue in the coming decades. Likewise, GDDs have also increased, and will continue to do so as mean temperatures increase in spring, summer, and fall. These changes will provide benefits to some summer crops like corn and soybean, but farmers will have to adapt to longer-season varieties to take advantage of this type of climate change. At some point in the not-to-distant future, farmers may be faced with a choice of whether to adopt a longer season variety of corn, or stay with what they've been doing and use the additional growing season length and GDDs in fall to get a cover crop in the ground instead to better protect the soil and help minimize erosion and take up stored soil nitrogen that remains after the summer crop is harvested.

The combination of warming temperatures and increased water vapor (dew point) will cause more strain on the health of livestock and in particular dairy cows during the summer. Warming during the colder seasons, however, will present challenges to other crops like winter wheat, cranberry and other fruit crops that require chilling units. Increased temperatures during late fall through early spring will also increase the likelihood that rain events could occur, causing more runoff from frozen ground. A smaller amount of snow cover available for melting and spring recharge of soil moisture could lead to increased failure of seed germination and more frequent occurrences of early growing season drought. Snow cover is also critical to protecting some crops like alfalfa from extremely cold soil temperatures during winter. Other complications of changing weather conditions during planting and harvest times will be a potential reduction in the number of workable field days. More extreme precipitation events, and prolonged wet periods during cooler time periods will further challenge farmers in completing necessary tasks in the field during both spring and fall.

References

Kucharik, C.J., S.P. Serbin, S. Vavrus, E.J. Hopkins, and M.M. Motew. 2010. Patterns of climate change across Wisconsin from 1950 to 2006. Physical Geography, 31: 1-28.

2A.2 Planting and Harvesting Dates

Author: Paul Mitchell

The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) published weekly crop progress reports for corn and soybeans, Wisconsin's two most significant crops. These reports give the percentage of acres having competed key management or crop phenology milestones each week, such as planted, emerged and harvested. Analyzing these data shows trends in these major crop milestones over the years. Previous research has shown trends toward earlier planting for corn in many states, with Wisconsin reaching 50% of acres planted more than a week earlier between 1979 and 2005 (Kucharik 2006).

Updating this research to include more recent data, expanding crop milestones, and adding soybeans shows that these trends have reversed. Specifically, the day for 50% planting, 50% emergence and 50% harvest for corn and soybeans in Wisconsin has been updates. These trends show that the trend for earlier planting and emergence reversed in Wisconsin around 2000 for corn and 2005 for soybeans. Specifically, in 2000, the projected day that half of the state's corn acres would be planted was May 14, but by 2019 it was May 19 – five days later. For soybeans, the change between 2000 and 2019 for the day of 50% planting was six days later, from May 23 to May 29. For crop emergence, the change is similar – the projected day for 50% of acres emerged is six days later for corn and four days later for soybeans than it was twenty years ago. Harvest is also later now – between 2000 and 2019, the projected day for 50% of acres harvested is nine days later than it was twenty years ago. As a result, the cropping season (days from planting to harvest), has become three to four days longer in the last twenty years. Wisconsin is not unusual; though the specific numbers vary across states, these same trends occur in other Midwestern states.

The duration of these activities has also changed over this same period, based on the projected number of days to go from 10% to 90% of acres planted, emerged or harvested. For corn, the planting period is now six days longer than it was in 2000, but a day shorter for soybeans. The emergence period for corn is unchanged between 2000 and 2019, but eight days longer for soybeans. Over this same period, the harvest period has gotten longer for both crops – by 2.5 days for corn and 11 days for soybeans.

Analysis to identify causes for these changes in planting, emergence and harvest remains to be conducted, but these observed trends are the outcome from a mix of weather and management decisions. Though average growing degree days have increased, springs have also become wetter in Wisconsin and extreme precipitation events more common – including both rainfall and timing of fall snowfalls – creating management challenges for Wisconsin crop farmers. Farmers can mitigate some of these challenges by investing in more equipment and workers to complete more work when management windows are open, or in new technologies to allow operations in more challenging conditions. Crop genetics, seed treatments and other in-furrow treatments can also be used to achieve better emergence and stands. These same investments and inputs can also be used to take advantage of climate change – the longer growing season and more growing degree days.

References

Kucharik, C. 2006. A Multidecadal Trend of Earlier Corn Planting in the Central USA. Agron. J. 98:1544-1550. doi:10.2134/agronj2006.0156

2A.3 Climate Change and Plant Disease Impacts

Author: Damon L. Smith

Corn and soybean are major field crops in Wisconsin and the entire United States. With 6 million acres or more in Wisconsin planted to corn and soybeans each year, they are important crops affected by climate impacts. Corn and soybean are susceptible to an array of disease-causing microbes that can require significant costs for the farmer and to the environment, due to the application of pesticides to control them. A major premise of the study of plant pathology is the idea that for diseases of plants to occur there must be the presence of a virulent pathogen, on a susceptible host, when the environment is favorable (host, pathogen, and environment are the legs of the triangle). This last factor stands to be a major driver of plant disease. In fact, the environment can influence when and where pathogens will cause disease problems and changing climate can result in the occurrence of new diseases affecting corn and soybeans.

Recently a new pathogen of tropical origin became a significantly problem on corn in Wisconsin. Prior to 2015 tar spot (caused by the fungus *Phyllachora maydis*) was not known to occur in the continental U.S (Kleczewski et al., 2020). However, it arrived in Illinois and Indiana that year and caused a small outbreak. Thought to have been spread by frequent hurricane events as a result of warming climate, significant rain events further exacerbated the disease, by providing an abnormally wet environment. In Wisconsin the disease has become established since 2016 with a major yield-limiting epidemic occurring in 2018. The 2018 epidemic caused significant losses for farmers in the state requiring some to resort to frequent fungicide applications. In Wisconsin the pathogen can overwinter, and epidemics initiate each year (Groves et al., 2020). The severity of the epidemics depends on when the disease starts relative to corn growth stage and the amount of rainfall. Since the first infestation in 2016 in Wisconsin, wetter and warmer summers have resulted in consistent epidemics that cause yield reductions and harvest disruptions for farmers. Thus, pesticide applications have increased further exacerbating the environmental impacts of climate change.

In soybean similar issues exist as in corn. For example, frogeye leaf spot (caused by the fungus *Cercospora sojina*) has been an increasing problem in the upper Midwest. In recent years this pathogen has become a more significant issue, causing severe epidemics in states where it traditionally had not been a problem, including Wisconsin. It is thought that due to climate change, the fungus is able to survive warmer winters (Roth et al., 2020). In addition, warmer growing seasons result in wetter growing seasons, meaning wind-dispersed rain and splashing rain are prominent for dispersal of the frogeye leaf spot pathogen. High humidity also makes for conducive conditions for disease development and high severity. Like corn, continued epidemics of this disease will impact the environment further as farmers are left to apply more pesticides to offset the damage frogeye leaf spot can cause.

Plant breeders must not only focus on breeding crops to be adaptable to climate change but should also focus on breeding for resistance to new and emerging pathogens that haven't traditionally been an issue. Resistant, adapted cultivars and hybrids will be a critical, sustainable, and environmentally friendly tool for managing these disease issues as the climate continues to change. Breeding technologies should also be adopted, such as RNA interference technology, that can speed the process of obtaining cultivars and hybrids with high-levels of disease resistance that don't have to be sprayed with pesticide.

References

Groves, C.L., Kleczewski, N.M., Telenko, D.E.P., Chilvers, M.I., and Smith, D.L. 2020. *Phyllachora maydis* ascospore release and germination from overwintered corn residue. Plant Health Progress. https://doi.org/10.1094/PHP-10-19-0077-RS.

Kleczewski, N., Plewa, D., Bissonnette, K., Bowman, N., Byrne, J., LaForest, J., Dalle-Lana, F., Malvick, D., Mueller, D., Chilvers, M., Paul, P.A., Raid, R., Robertson, A., Ruhl, G., Smith, D.L., and Telenko, D.E.P. 2020. Documenting the spread ,establishment, and severity of tar spot, caused by *Phyllachora maydis*, in the United States corn crop. Journal of Integrated Pest Management. https://doi.org/10.1093/jipm/pmaa012.

Roth, M.G., Webster, R.W., Mueller, D.S., Chilvers, M.I., Faske, T.R., Mathew, F.M., Bradley, C.A., Damicone, J.P., Kabbage, M., and Smith, D.L. 2020. Integrated Management of important soybean pathogens of the United States in changing climate. Journal of Integrated Pest Management. https://doi.org/10.1093/jipm/pmaa013.

2A.4. Invasive plant species

Author: Mark Renz

Presence and competitiveness of weeds/invasive plants is determined by a range of factors. While site specific attributes (e.g. soil type) and land management approaches can be drivers, environmental factors influenced by climate are often highly influential. Documentation of spread, and the factors responsible for this spread, has historically been limited. Recent research and other efforts are improving our understanding of the drivers of current and potential spread of weeds and invasive plants.

In agronomic crops recent expansion of common waterhemp and palmer amaranth has been observed at a national, regional, and local (Wisconsin) level. While one driver of spread is from herbicide resistance and the ability of seed to move through contaminated equipment, research has also suggested spread is also impacted by annual temperature, with lower values limiting northward range expansion. Research suggests a warming climate may facilitate further spread north (Runquist et al 2019). While other agronomic weeds have been studied, the complexity of the interaction of changing climate with crops grown and management methods prevent any sweeping conclusions. Additional research is required to elucidate short- and long-term changes in weed communities and competition within specific cropping systems.

In non-crop/natural areas efforts at predicting species able to move into new habitats has been substantial. Over 800 species were modeled at a national level to predict which would increase, remain the same, or decrease their potential, suitable habitat (range). Results found 23 species that would likely increase their range in Wisconsin (Allen et al. 2016). Other research within Wisconsin found significant potential increases in suitable habitat for Japanese barberry and Phragmites under future climate scenarios (Jorgensen 2020). While expansion was projected in a range of habitats, the magnitude of expansion is unclear.

Additionally, non-climatic variables (e.g. tree canopy cover) are likely to also change adding complexity into spread potential as these effects are rarely evaluated with changing climate. Federal and state agencies have emphasized watch lists for potential range shifting-species that may appear (https://www.eddmaps.org/rangeshiftlisting/). This coupled with aggressive management of established, but small populations is hopeful at limiting impact. This information is being incorporated into land management plans and likely will be updated periodically as more information exists. Similar to agronomic weeds, the interactions between invasive plants with other species and management likely will cause complex-, site- and species-specific changes in spread of many of these species, thus additional research is required to understand these interactions and impacts.

References

Allen, JM and BA Bradley. 2016. Out of the weeds? Reduced plant invasion risk with climate change in the continental United States. Biological Conservation 203:306-312,

Jorgenson, N. 2020. Validating the ability of habitat suitability models to predict new populations of invasive plants: implications for improved land management

Dissertation, University of Wisconsin-Madison. December 2020.

Runquist, RDB, T Lake, P Tifn, DA Moeller. 2019. Species distribution models throughout the invasion history of Palmer amaranth predict regions at risk of future invasion and reveal challenges with modeling rapidly shifting geographic ranges. *Scientific Reports* 9:1-12.

2A.5 Extreme weather events

Authors: Chris Kucharik and Damon Smith

Climate change will increase the frequency of extreme weather events (e.g. heavy rains, false springs, droughts, floods). The most notable impacts to date in Wisconsin have been heavy rainfall events and prolonged periods of above average precipitation, as well as increased variability in weather which could also increase the likelihood of flash droughts or even longer term droughts that have not occurred frequently in the past decade (although one is occurring in 2021 at the time this report is being written), which was Wisconsin's wettest ever recorded.

Given that groundwater is relatively shallow in many portions of Wisconsin, the sustained wet period of 2011-2019 (and even extending back to 2007-08) created many new lakes across the Wisconsin landscape due to groundwater flooding, and those elevated water levels did not recede quickly (if at all) during that period. This caused loss of farmland that could no longer be planted – at least temporarily for at least several years to a decade or longer. An increase in extreme weather events can damage large expanses or cropland or impact crops during climate-sensitive stages of their life cycle, like the floating leaf stage of wild rice. Increased frequency of rainfall and cooler and cloudy weather during the springtime has effectively halted a longer-term trend towards earlier springtime planting of summer crops (Kucharik 2006; Kucharik 2008)

Another impact of wetter weather during the growing season is the increased risk of plant disease on the major crops of the state. Many fungal and bacterial pathogens thrive when weather is wet. Increasing the frequency of wetting events, or lengthening the duration of these events, can lead to sustained and significant disease epidemics that can not only reduce crop yields but lead to increase input costs for farmers to try to mitigate these problems. Cool, wet weather from 2014 – 2019 led to sustained epidemics of white mold on soybean. The pathogen (*Sclerotinia sclerotiorum*) thrives during cool wet conditions, especially when this occurs during or after soybean bloom.

Higher amounts and frequency of rain in late July and August (when historically Wisconsin is a bit dryer) led to very conducive conditions for this pathogen and significant epidemics for farmers to deal with. Farmers lost revenue not only due to yield loss, but also the increased need to apply foliar fungicides during the bloom period. It is expected that there will continue to be an increased frequency of these events as climate continues to change.

References

Kucharik, C.J. (2006). A multidecadal trend of earlier corn planting in the central U.S. Agronomy Journal 98,1544-1550.

Kucharik, C.J. (2008). Contribution of planting date trends to increased maize yields in the central United States. Agronomy Journal 100, 328-336, doi:10.2134/agronjnl2007.0145.

2A.6. Overwinter Survival

Author: Gregg Sanford

As winter temperatures warm, the extent, depth, and persistence of snow cover in Wisconsin is projected to decline.[1] The frequency and duration of associated winter "thaws" are also likely to increase. These changes may have significant implications for the overwintering potential of perennial forage crops like alfalfa and winter cereal grains (e.g., winter wheat). Winterkill in these crops is typically caused by one of four factors tied to winter temperature and snow cover. These include: 1) a lack of insulating snow cover, 2) ice sheeting, 3) frost heaving, or 4) a premature break in dormancy.

Once dormant, both perennial forages and winter cereals can tolerate temperatures well below freezing (32˚F). Dormant alfalfa varieties can survive 4-inch soil temperatures of 13 to 15˚F and winter wheat can typically survive the winter if crown temperatures do not drop below -1 to 3˚F.[2,3] Cold weather systems often drive winter air temperatures, even in southern Wisconsin, below these thresholds.

Insufficient snow cover during extremely cold weather exposes crown and root tissues to freezing, cell lysis, and death.

Ice sheeting occurs when snow melts during mid-winter thaws and then refreezes on a crop field. When this occurs, it prevents gas exchange and root respiration. Prolonged periods of ice cover (3 to 4 weeks) can suffocate and kill or significantly injure the crop.

Frost heaving occurs when soils warm above freezing during the day and then refreeze at night. This cycle of freeze and thaw causes the soils to expand and contract, pushing crowns up and out of the ground. Once above the soil surface the crown and exposed root tissue is vulnerable to freezing temperatures.

A ***premature break in dormancy*** can occur during prolonged spells of warm winter weather. When this occurs the crop loses its ability to withstand freezing temperatures and is vulnerable to subsequent cold weather.

References

Notaro M, Lorenz D, Vimont D, Vavrus S, Kucharik C, Franz K. 21st century Wisconsin snow projections based on an operational snow model driven by statistically downscaled climate data. *Int J Climatol*. 2011;31:1615-1633. doi:10.1002/joc.2179

John RP, Megan G. Temperatures and the growth and development of wheat: a review. *Eur J Agron*. 1999;10:23-36. %5C%5CGRAEFE%5CJournals%5CEuropean_Journal_of_Agronomy%5C_3.pdf.

Cosgrove D, Undersander D. Evaluating and managing alfalfa stands for winter injury. *Focus Forage*. 2003;5(8):1-3. https://fyi.extension.wisc.edu/forage/files/2014/01/StandEvaluationFOF.pdf.

B. Impacts by agriculture sector

2B.1. Animal Agriculture

Authors: John Shutske, Jenna Pavela, and Paul Stoy

Warming temperatures have significant implications for animal comfort and production based on the physiology of the animals themselves. Cows and other ruminants thrive in cooler conditions and need cool nights.

Future climate changes that impact cropping systems – including feed and forages for animals – lead to production challenges. Feed production is influenced by increased moisture, heat, humidity, and increased pest pressure, all of which result in lower feed quality before and after storage.

The increased frequency, severity and overall risk levels from extreme events has direct deleterious impacts on the animals themselves as well as production systems including buildings, facilities, feeding systems, and storage. This includes increased frequency and severity of events that include:

- Floods
- Droughts
- Heavy snowfalls
- Day-to-day variation/extremes -- animals tend to do better with stable and/or gradual weather fluctuations rather than 30 degrees one day and 80 the next, especially common in early spring and in the fall.

- Utility and transportation interruptions (e.g. downed power lines, road closures, feed/product shipment on waterways including the rivers and Great Lakes)

There are significant implications for agricultural design engineers who work on animal housing and comfort to address cooling, ventilation, snow loads, water & moisture handling, energy demands (especially for cooling), and product storage facilities and practices (grain, hay, silage, etc.). This likely means careful consideration in the maintenance and updates to standards, design, regulatory codes, and more.

We have the potential to see new animal diseases and changes in existing diseases – including new/emerging pathogens, changes in vectors for disease as a result of climate changes, and changes in environmental factors (including less severe winters and more standing water as examples). These new disease threats pose potential health threats both to livestock/dairy animals and potentially to workers and the broader public in Wisconsin.

For livestock (including dairy) producers, there will be pressures associated with having a land base suitable for nutrient cycling. At times of the year, there may be fewer suitable and environmentally acceptable “dry” acres for manure application adding to the challenge and pressures on producers.

References

Alan Rotz, C., Howard Skinner, R., Stoner, A. M., & Hayhoe, K. (2016). Farm simulation can help dairy production systems adapt to climate change. *Improving Modeling Tools to Assess Climate Change Effects on Crop Response*, *7*, 91–124.

Babinszky, L., Halas, V., & Verstegen, M. W. (2011). Impacts of climate change on animal production and quality of animal food products. *Climate Change Socioeconomic Effects. Rijeka: InTech*, 165–190.

Backlund, P., Janetos, A., & Schimel, D. (2008). The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. *Synthesis and Assessment Product 4.3. Washington, DC: US Environmental Protection Agency, Climate Change Science Program. 240 p.*

Berman, A. (2005). Estimates of heat stress relief needs for Holstein dairy cows. *Journal of Animal Science*, *83*(6), 1377–1384.

Grossi, G., Goglio, P., Vitali, A., & Williams, A. G. (2019). Livestock and climate change: Impact of livestock on climate and mitigation strategies. *Animal Frontiers*, *9*(1), 69–76.

Key, N., Sneeringer, S., & Marquardt, D. (2014). Climate change, heat stress, and US dairy production. *USDA-ERS Economic Research Report*, *175*.

Koneswaran, G., & Nierenberg, D. (2008). Global farm animal production and global warming: Impacting and mitigating climate change. *Environmental Health Perspectives*, *116*(5), 578–582.

Konkle, Darlene. Personal communication, Zoom Call. March 16, 2021.

Lacetera, N. (2019). Impact of climate change on animal health and welfare. *Animal Frontiers*, *9*(1), 26–31.

Liang, X.-Z., Wu, Y., Chambers, R. G., Schmoldt, D. L., Gao, W., Liu, C., Liu, Y.-A., Sun, C., & Kennedy, J. A. (2017). Determining climate effects on US total agricultural productivity. *Proceedings of the National Academy of Sciences*, *114*(12), E2285–E2292.

Tao, S., Dahl, G. E., Laporta, J., Bernard, J. K., Orellana Rivas, R. M., & Marins, T. N. (2019). PHYSIOLOGY SYMPOSIUM: Effects of heat stress during late gestation on the dam and its calf. *Journal of Animal Science*, *97*(5), 2245–2257.

Wattiaux, Michel. Personal Communication, Zoom Call. March 23, 2021.

West, J. W. (2003). Effects of heat-stress on production in dairy cattle. *Journal of Dairy Science*, *86*(6), 2131–2144.

2B.2. Grazing systems

Authors: Rachel Bouressa, Diane Mayerfeld[1], Laura Paine, Gene Schriefer[1]

Experience within Wisconsin's well-established grazing community suggests that managed grazing systems have thus far been largely resilient to climate change. In fact, increased adoption of managed grazing could help local communities adapt to increased precipitation as well as more erratic and intense rainfall events, which are projected to impact Wisconsin in the future.[1,2] For example, in 2019 many corn and soybean farmers in the state were unable to plant their crops due to excessive rain. Rather than negatively impacting grazing operations, perennial cool-season(C3) pastures grew well in 2019, and grazing livestock were able to access pastures even when farm machinery was unable to get into the field.

In addition, land in well-managed perennial pasture helps slow water runoff, increase infiltration, and absorb and retain much more rain than land in annual crops. This ability to absorb rainfall can reduce the severity of flooding and damage to infrastructure such as roads and bridges. In contrast to annual row crops, perennial pastures are also far less susceptible to damage caused by severe windstorms like those experienced in Wisconsin in 2019 and in Iowa in 2020. Well-managed pastures are also some of our best land management strategies for building and retaining soil carbon, helping to reduce atmospheric carbon dioxide concentrations, as well as providing a host of other critical ecosystem services (e.g. erosion control, water purification).[3–6]

[1] UW-Madison, Division of Extension, Outreach Specialist

While well-managed pastures are equipped in many ways to adapt to a changing climate, there are several challenges grazing systems will likely face and need to overcome.

These include:

- ***Difficulty making hay*** – Wet and humid weather makes putting up dry hay a challenge and can result in both loss of yield and quality. This is especially problematic in early summer.
- ***Heat and drought*** – Cool-season pastures are more likely to suffer yield losses from brief periods of drought than warm-season(C4) annuals such as corn. In extended hot dry conditions, such as those the US experienced in 2012, Wisconsin's primarily cool-season pastures go dormant, and grazing farms that do not pre-buy and store feed for summer and fall are vulnerable to feed shortages. Increased heat may lead to faster maturation of cool-season grasses, which reduces forage quality and animal production.
- ***Animal health and wellbeing*** – Increased temperatures (both daytime and nighttime) can have significant health and production impacts for livestock that are outdoors.
- ***Winterkill*** – Fluctuating winter temperatures can exacerbate winter kill of pasture and other perennial forages, leading to feed shortages the following year.
- ***Erratic weather*** – Unpredictable seasonal weather (moisture, heat) makes planning and stocking decisions more difficult, and producers will need increased flexibility to manage around this variation.

Grazing farms are trying a variety of adaptation strategies to cope with the impacts of climate change.

These include:

- ***Warm-season grasses***: Warm-season grasses can provide high yielding, quality forage during hot, dry spells. This includes warm-season perennial grasses like switchgrass, Indiangrass, or big bluestem, as well as annual C4 grasses like sorghum and sorghum x sudangrass hybrids.
- ***Stockpiling*** - Some farms store additional hay and stockpile extra warm and/or cool-season pasture to provide a buffer against challenging weather.
- ***Silvopasture*** – Silvopasture, the integration of trees in grazing systems, can provide shade and emergency forage.
- ***Shade*** – portable shade structures and sprinkler systems can provide relief from heat stress to grazing livestock.
- ***Insurance*** – Some farms are buying pasture and range insurance policies in case of bad weather. https://www.rma.usda.gov/Fact-Sheets/National-Fact-Sheets/Pasture-Rangeland-Forage-Pilot-Insurance-Program

- ***Adapted forages and livestock*** – Farms are experimenting with forage varieties that can withstand extremes in moisture, including both excessive rain and drought conditions. In addition, farmers are interested in information on livestock breeds and characteristics that can thrive on pasture in these weather extremes.

Although climate change poses challenges for grazing farms, in the long-term Wisconsin farms will be better positioned to support cattle on grass than the southern and western US, which relies on shrinking aquifers to irrigate forage crops like alfalfa.

References

Kucharik C, Serbin S, Vavrus S, Hopkins E, Motew M. Patterns of climate change across Wisconsin from 1950 to 2006. *Phys Geogr*. 2010;31(1):1-28. doi:10.2747/0272-3646.31.1.1

Wisconsin Initiative on Climate Change Impacts. Trends and projections. https://wicci.wisc.edu/wisconsin-climate-trends-and-projections/. Published 2021. Accessed April 26, 2021.

Sanford GR, Posner JL, Jackson RD, Kucharik CJ, Hedtcke JL, Lin TL. Soil carbon lost from Mollisols of the North Central U.S.A. with 20 years of agricultural best management practices. *Agric Ecosyst Environ*. 2012;162:68-76. doi:10.1016/j.agee.2012.08.011

Franzluebbers AJ, Paine LK, Winsten JR, et al. Well-managed grazing systems: A forgotten hero of conservation. *J Soil Water Conserv*. 2012;67(4):100-104. doi:10.2489/jswc.67.4.100A

Cates AM, Ruark MD, Hedtcke JL, Posner JL. Long-term tillage, rotation and perennialization effects on particulate and aggregate soil organic matter. *Soil Tillage Res*. 2016;155:371-380. doi:10.1016/j.still.2015.09.008

Jokela W, Posner J, Hedtcke J, Balser T, Read H. Midwest cropping system effects on soil properties and on a soil quality index. *Agron J*. 2011;103(5):1552-1562. doi:10.2134/agronj2010.0454

2B.3 Grain crops

Author: Chris Kucharik

Southern and western Wisconsin typically have the highest corn and soybean yields in Wisconsin where long-season hybrids and varieties with higher yield potential can be planted. The lowest average yields are harvested in the northeast where short-season hybrids and varieties dominate. This is due to the significant gradient in annual average temperature and growing season length from the southwestern to northeastern Wisconsin; this pattern of productivity and harvested area (Fig. 2) is roughly dissected by an ecological *tension zone* across the state, which could potentially shift with future climate change. The tension zone roughly divides the northern forest ecotone in Wisconsin from the southern prairie, oak savanna, and now agriculture-dominated landscape. The average growing season lasts as long as 170 days over southern and far western portions of Wisconsin, but only up to 130 to 140 days in the central and north. These general spatial patterns cause total growing degree-days (GDD; base 10 ºC from April 1 through September 30, inclusive) to range from 1100 ºC in the far northwest to near 1500 ºC in the far south (Kucharik, 2008), thereby driving a wide variation in hybrid selection.

Corn and soybean yield trends across Wisconsin have generally been favored by cooling and increased precipitation during the summer growing season (Kucharik and Serbin 2008). It appears that a significant amount of spatial variability in climate trends has led to highly variable trends of soybean and corn yields at the county level since the 1970s. Some regions with the highest yield gains over the 1976-2006 period experienced a trend towards cooler and wetter conditions during the summer, while other areas that have experienced a trend towards drier and warmer conditions have experienced suppressed yield gains. There is no apparent latitudinal gradient of climate changes or yield trends (Kucharik and Serbin 2008). Given that the magnitude of recent temperature changes are 0.1 to 0.3 ºC decade^{-1}, which are on the lower end of the projected rate of temperature increases through the end of the 21st century, there is strong evidence that Wisconsin summer cropping systems like corn and soybean will continue to be challenged by future climate change.

It appears that more widespread suppression of yield gains across the state would have resulted had many counties not experienced an increase in precipitation since the 1970s (Kucharik and Serbin 2008). We also know that the frequency of extremely hot days (e.g. > 90 ºF) has not been increasing everywhere across Wisconsin, and the large majority of warming during the summer season has occurred during nighttime which tends to increase precipitation and humidity. However, future climate projections suggest the frequency of daytime highs during summer > 90ºF will increase considerably, putting summer crops at risk for more heat and drought related stress. It is more likely that by the middle of the current century, the average summer conditions will look more like what we experienced in 2012 when crops faced widespread heat and drought stress.

A trend towards warmer and drier conditions during the spring planting time and fall harvest will undoubtedly help boost yields in northern and central regions of Wisconsin that currently experience a shorter growing season compared to points further south; this forces farmers to choose crop hybrids and varieties with lower yield potential due to their planting in a shorter growing season region. Farmers are likely to be aware of, and will adjust to, changes in springtime conditions given they are always looking to get their crops into the ground as early as possible to place higher-yielding hybrids and varieties in northern regions. It is already understood that the arrival of spring has been occurring earlier in Wisconsin (Kucharik et al. 2010). However, if warming would continue to occur during the middle of the growing season, it could work against crop productivity by accelerating phenological development, causing the plant to mature more rapidly, losing valuable calendar days in the field to accumulate biomass during grain fill.

Furthermore, additional heat and soil moisture stress during pollination and an increased frequency of very warm days could counteract the potential benefits of an extension of the growing season via decreased rates of carbon uptake through photosynthesis due to increase heat and water stress, as well as directly interfering with pollination in corn via asynchrony between silk development and pollen shed, or silk desiccation. Such 'phenological mismatches' can also occur between crops and native pollinators as changes in springtime temperature increase insect and crop activity at different rates.

In summary, increased temperatures during the springtime will help to facilitate earlier seed sowing and improve early season vigor and root development, but additional heating during the mid-summer during flowering or grain-fill could effectively cause an increased rate of development, increase respiratory loss and cause total photosynthetic uptake to decrease, leading to lower yields. In contrast, springtime temperatures that are too cool can impede seed germination and the rate of development and also decrease yields.

In the case of precipitation, extremely low and high values tend to decrease yields because these conditions are often associated with extended dry periods and drought or flooding and decreased radiation, but above average precipitation in July and August are usually associated with higher yields. However, higher precipitation is often generally correlated with lower temperatures, particularly in late spring, which can delay planting and lead to lower yields. While GDD fluctuations from year to year can impact yield variability, it is still hypothesized that variability in summertime precipitation is the dominant factor contributing to year-to-year fluctuations in yields from expected values.

References

Kucharik, C.J., S.P. Serbin, S. Vavrus, E.J. Hopkins, and M.M. Motew. 2010. Patterns of climate change across Wisconsin from 1950 to 2006. Physical Geography, 31: 1-28.

Kucharik, C.J. and S.P. Serbin (2008). Impacts of recent climate change on Wisconsin corn and soybean yield trends. Environmental Research Letters 3 034003 (10pp) doi: 10.1088/1748-9326/3/3/034003.

2B.4 Specialty crops

Author: Jed Colquhoun

Production and processing of specialty crops in Wisconsin are important to both state and national agricultural, as well as manufacturing industries. Wisconsin ranks 7th among US states for farmgate vegetable sales and 8th for farmgate fruit and tree nut sales. While a portion of these sales enter fresh markets (grocery stores, restaurants, farmers markets, etc.), a significant amount of Wisconsin farmgate sales go to processors for freezing, canning, drying, and pickling. As a result, Wisconsin ranks 2nd among US states for both harvested acreage and total production of processing vegetables and 3rd for production value. Key processing crops in Wisconsin include potatoes, sweet corn, green beans, green peas, carrots, cucumbers, and onions, with cranberries by far the leading fruit. In addition, Wisconsin is a world-renowned producer of ginseng, most of which is exported to Asia.

i. Cranberry

Cranberry production is unique among Wisconsin crops in that it requires detailed attention to agronomic inputs and practices and hydrological management to be successful. As such, a changing climate not only affects how the crop is grown, but it has effects on how growers manage water on the marsh to optimize that growth. Inconsistent (or highly variable?) temperature is likely the most detrimental variable for cranberry production in a changing climate. For example, cranberry growers flood production beds in early winter to produce an ice layer that protects the plant structures below the ice layer from below freezing temperatures. This practice allows cranberry vines to continue to grow and respire in what is effectively an ice terrarium. However, repeated and increasingly more frequent freeze-thaw cycles resulting in oscillating temperatures in recent years have made it difficult to produce and maintain the ice layer that protects the crop.

From an agronomic standpoint, fluctuating spring temperatures and recent “false springs”, where unseasonably warm temperatures early in the year are followed by below freezing temperatures, have the impact of disorienting plant growth, subjecting premature spring growth to the susceptibility of frost or freeze damage. In the worst situations, these false springs have caused cranberry plants to bloom sporadically as early as May in recent years, which requires continued and vigilant frost protection via sprinkler irrigation to prevent crop loss.

Switching to more resilient cranberry cultivars that have improved mid-winter cold tolerance may be a long-term solution that will require substantial research efforts. A medium-term prospect to add resilience across the farm could be to grow supplemental crops in addition to cranberry that would bridge gaps in poor cranberry production years. Unlike most Wisconsin farms, most marshes currently only produce cranberries. A short-term prospect is the use of new cryoprotective products to protect new growth from cold damage.

ii. Orchards and vineyards

Similar to cranberry, perennial tree fruit and grape plantings are subject to long-term damage from frost and freeze damage at susceptible growth stages. Like in cranberry, in recent years these fruit crops have also been “tricked” into blooming early by “false springs” followed by a return to below freezing temperatures, which can eliminate that season’s fruit crop and can cause longer-term plant damage. However, unlike cranberry production, orchards and vineyards cannot be covered by a layer of protective ice, which makes these crops much more vulnerable to extreme cold damage as with the two polar vortices we have experienced in the last decade.

On the positive side, a warming climate combined with plant breeding for regional resilience may allow for some fruit crops, such as table grapes and hardy kiwi, to be grown further north than in the past, allowing farms to diversify their cropping portfolio. However, these crops are subject to the same fluctuating temperature risks outlined above. As perennials, new fruit crops also require a high initial establishment investment and several years growth until production is optimized. Moreover, these crops may require some additional equipment and processing infrastructure to accommodate these newer fruit options.

iii. Processing vegetables

The vast majority of large-scale processing vegetable production occurs under the purview of national or multi-national food processing companies. This scale allows processors to manage crop distribution across several production regions in a way that's likely more nimble than most agricultural production systems. They own the harvest equipment and hire specialized crop expertise, both of which can be mobilized to grow specific crops where the climate is most conducive and over large geographies. In many senses, Wisconsin has benefited from maintaining or building processing vegetable acreage because the Central Sands region, where most of these crops are grown, offers a forgiving coarse-textured soil that drains well in wet years and can be irrigated in dry years. This benefit comes with some risk, such as overdrawing groundwater for irrigation in droughty years. Also, water quality concerns such as nitrate contamination in wet years where high precipitation events can cause excessive leaching. Research is currently underway to look at ways to conserve and protect water resources, such as through variable rate irrigation, cover cropping, and biologically-based inputs.

In general, the processing vegetable sector in Wisconsin has benefited from longer growing seasons. However, longer seasons have not been consistent or predictable enough for the processors to significantly modify and move toward earlier seeding or later harvest dates in substantial (and predictable) ways. Thus, the benefit from warming is primarily realized in an extended fall harvest, where the last seedings that often were killed by frost prior to maturity a few decades ago have recently lived until harvest absent below freezing temperatures. This extended harvest has a positive ripple effect that benefits the growers and allows processing plants to stay open—often employing local workers longer into the fall.

iv. Potato

The issues related to water described for cranberry and processing vegetables above are even more pronounced for potato production systems, likely representing the greatest climate-change related risk as well as potential asset in our production system. Potato production requires a forgiving, light soil that allows for uniform tuber development and appearance that consumers demand. These soils also provide for adequate drainage to reduce soil-borne disease pressure that can make potato tubers unmarketable. However, production on such coarse-textured, low organic matter soils also requires supplemental irrigation and nitrogen.

Precipitation variability and longer growing seasons make water and nitrogen management in potato very challenging. In droughty years such as 2012, groundwater withdrawals to irrigate potato and rotational crops led to groundwater level reductions in nearby streams and lakes that are essentially low elevation spots where the groundwater is exposed. In excessively wet years like 2018, managing plant nutrition to produce an economically viable potato crop led to the risk of leaching nitrogen and other inputs into shallow groundwater. From the growers' standpoint, managing fertilizer inputs around unpredictable, localized high precipitation has become increasingly challenging in recent years. Excessively wet fall seasons, such as in 2018, also challenge the ability to harvest and store potato crops, subjecting tubers to high plant disease risks during the subsequent winter and spring storage seasons.

Developing resilient potato varieties that are disease resistant and tolerate reduced nitrogen and water inputs could eventually lead to positive strides in addressing these challenges, but without consumer acceptance of modern genetic modification in direct consumed crops, this process has been slow using traditional plant breeding. The production system could also benefit from including low input, yet marketable crops in the rotation, such as dry bean, in lieu of other high nitrogen and water demanding crops like field corn. Smaller positive strides may be made by modifying the production system to integrate perennial cover crops, slow-release fertilizers, variable rate irrigation, real-time nitrate sensing in irrigation water and other diversified strategies.

V. Changes in Insect Phenology

Author: Russ Groves

The Colorado potato beetle (CPB), *Leptinotarsa decemlineata*, is a major pest of multiple solanaceous crops including potatoes, tomatoes, and eggplants. These insects are well-known for their ability to develop insecticide resistance to nearly all the major classes of insecticidal compounds labeled for their control. A very common method used to control these insect pests over the past 20 years has included the use of at-plant applications of systemic neonicotinoid insecticides, defined by their mode of action Group 4A (IRAC International MoA Working Group, 2021; https://irac-online.org/).

When first registered in 1995 and applied at planting to potato seed, the neonicotinoid group of insecticides provided growers with nearly season-long control of CPB populations. Since its initial registration, however, CPB populations have developed significant levels of resistance to the compounds in the neonicotinoid group. Coincident with this observed resistance and associated lack of control have been notable changes in the emergence phenology of populations of CPB.

To further build on this idea, we now observe that populations of CPB have evolved a behaviorally adaptive, extended diapause (delayed emergence) mechanism enabled by a changing climate which allow later emerging beetles to avoid insecticide exposure through changes in behavioral emergence patterns to minimize insecticide exposure in time. Behavioral resistance to insecticides is defined as the ability of an insect to avoid a lethal dose of insecticide, through an adaptation of 'avoidance in time'.

It is possible that if CPB individuals which emerge from diapause later in the season tend to survive sublethal insecticide levels in the plant, this effect could favor the coevolution of tandem resistance mechanisms that are linked to both behavioral (diapause duration) and physiological (insecticide detoxification) factors that favor fitness of these phenotypes over a period of two decades of continuous systemic neonicotinoid use. In the absence of a changing climate and a longer production season, coincident changes in emergence phenology of the CPB would result in a temporal mismatch with food resources and could be very detrimental to population fitness.

VI. Small-scale diversified fruit and vegetable operations

Authors: Chelsea Chandler, Diane Mayerfeld, Claire Strader, John Hendrickson, Julie Dawson

Wisconsin has a large number of diversified small scale vegetable farms which sell fresh market vegetables, including directly marketing vegetables to local food consumers through farmers markets, Community Supported Agriculture (CSAs), farm stands and U-pick. These farms often direct-wholesale crops as well, supporting local grocery stores, restaurants and other retail food companies. CSA is a model of farming where members buy a share of a farm's produce in advance and receive produce throughout a growing season. Diversified fruit and vegetable farms that rely on direct markets are often smaller in size and big on diversity, growing dozens to hundreds of varieties of fruits and vegetables. This diversity can contribute to farm resilience in the face of climate change (if one crop fails, there are many others that can take its place).

However, climate change poses several challenges for diverse small-scale farms, including CSAs. Heavy precipitation events make planting and weeding all crops difficult. Harvesting root crops and tubers like carrots, sweet potatoes, and potatoes is also made difficult after rain events. Changing weather patterns can also increase disease pressure on crops. Cole crops in particular are becoming harder to grow without disease. Facing these challenges, some farms have elected to shift away from CSA and the crop diversity required by that model to finding other outlets for their produce.[2] Yet other former vegetable CSA farms have shifted from a focus on annual crops to more perennials – such as fruit orchards – in order to minimize soil disturbance and improve carbon storage.

Organic and smaller scale farms are using and helping test practices to adapt to and mitigate climate change – ranging from cover crops and reduced tillage to other options for an unpredictable climate such as increased use of hoophouses and seeking out stress tolerant, stable varieties.[3] Direct-market farmers can be important messengers, increasing awareness about the challenges climate change poses to our food systems and ways farmers can be part of solutions. Because of the direct farmer to eater relationship these farmers are uniquely suited to provide education to members on climate impacts, adaptation, and mitigation methods in agriculture.

Finally, because diversified vegetable farms' field footprint is typically much smaller than row crop farms, opportunities for conservation and climate mitigation measures on non-cultivated parts of these farms may exist. Forest or prairie restoration or siting of renewable energy systems may be easier in some cases because these farms typically have fewer cultivated acres and are less likely to push marginal land into production with fruits and vegetables. (Though vegetables are higher value, they also tend to be less forgiving and adaptable than some row crops.)

[2] https://daneclimateaction.org/OECC-Blog/CSAs-and-Climate-Change

[3] https://sites.google.com/view/climate-resilience-for-organic/home, Center for Integrated Agricultural Systems. Status of Organic Agriculture in Wisconsin 2021, forthcoming.

2B.5. Agricultural industry

Authors: Michelle Miller and Sarah Lloyd

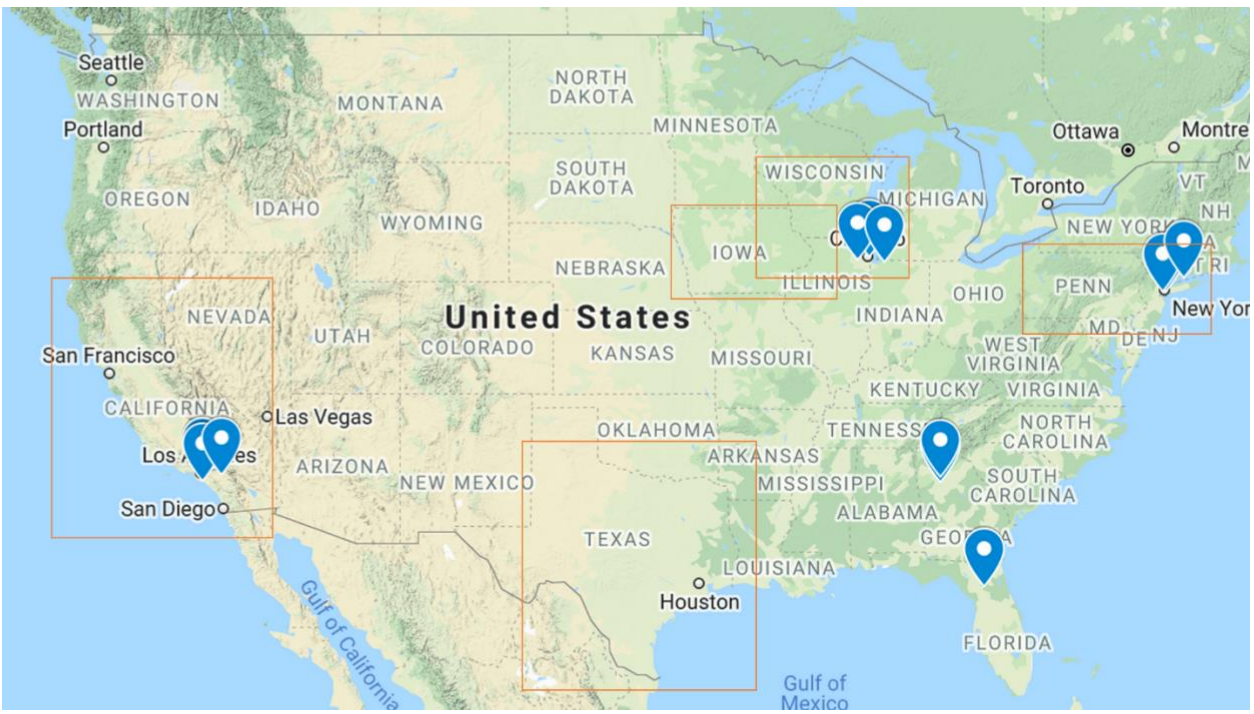
The current structure of our food system is dependent on GHG emissions. In addition to developing strategies for mitigation and adaptation of direct impacts on agricultural production from climate change, we must also develop strategies for dealing with disruptions to the system that moves agricultural products from field to fork. Improved food transport, distribution and refrigeration are high leverage strategies for both mitigation and adaptation to climate change (Rosenzweig et al 2020). Perishable foods distribution and consumption is the most energy-intensive aspect of the food system. Implementing ways to conserve energy within the current system, as well as overall system improvements are important mitigation and adaptation strategies.

Tello and DeMolina (2017) term this the "dis-ecology of scale". Instead of the current heavily extractive systems, their case for relocalizing the food system is to improve overall systems energy efficiency, and also to close nutrient cycles, improve biodiversity at a landscape scale, build on local, expert knowledge that farmers and practitioners possess, and make the urban-rural relationship fairer and more democratic. In addition, building supply chains that support and incentivize adaptive agricultural production systems that are more resilient to disruptions, such as increasing continuous living cover, grass-based and perennial practices should also be included in climate adaptation and mitigation strategies.

The National Research Council (2015) describes the food system as a complex adaptive system, where certainties and agreements shape behavior so that people interact to create a self-organizing system (Parsons 2007). For the last decade, the European Union has been investing in research to improve food distribution by improving how the system is organized overall (Armendaris et al 2016). They have quantified the value of centralized staging areas for improving logistical efficiencies, a key strategy for "horizontal collaborative logistics" (Pomponi et al 2013). Researchers found that "urban consolidation centers" achieve an overall reduction in costs (5%), reduction in CO_2 emissions (7%), reduction in vehicles used (10%), reduction in total distance traveled (19%), and an increase in total number of delivery points visited per trip (11%) (UTURN, 2018). Such efficiencies save the public and private sectors money and improve service to those in need. To know where collaborative logistics are best placed to realize these benefits, planners need to know the network structure for food flow.

The US food system is organized to move food across the continent. To better understand produce, meat, and dairy supply chains, researchers are mapping the network structure for cold-chain perishable foods (packing and processing, refrigerated trucks, cold storage warehouses, electric charging stations, etc.). Network analysis of the food system using the 2007 and 2012 Commodity Flow Survey describe how all agricultural products move through the U.S.. Aggregating data for seven agricultural categories, including large-scale grain movements, researchers identified nine core nodes within a network of 123 nodes, with 4,198 links between nodes. The core nodes play a central role in network architecture for agricultural products. Core nodes are vulnerable to disruption and may catalyze a cascade disruption to food movement throughout the USA. (Lin et al. 2014, 2019; Konar et al., 2018).

Ongoing collaborative work at University of Illinois Urbana Champaign and University of Wisconsin - Madison and other national partners is examining node density, degree, strength, affinity, clustering, direction, betweenness centrality and triadic analysis using 2017 data released in 2021. This work can help identify secondary and tertiary nodes in the system, or the lack of them, in any geographical region. It will allow researchers and planners to identify where infrastructure is needed to rebalance food flow between consumption and production regions to improve system organization. Findings will be used in an on-going project to document regional scale contributions to systems resilience. The upper Midwest region is one of the study focus areas.



Core nodes identified in Lin, et. al. 2014: Los Angeles-Long Beach-Riverside; Chicago-Naperville-Michigan City; Remainder of Texas; Remainder of Pennsylvania; New York-Newark-Bridgeport; Iowa; Remainder of California; Remainder of Wisconsin; Atlanta-Sandy Springs-Gainesville.

References

Armendariz, V, S. Armenia, and S.A. Atzori. 2016. “Systemic Analysis of Food Supply and Distribution Systems in City-Region Systems—An Examination of FAO’s Policy Guidelines towards Sustainable Agri-Food Systems,” *Agriculture* 6(65). https://doi.org/doi:10.3390/agriculture6040065.

Konar, M., X. Lin, B. Ruddell, and M. Sivapalan. “Scaling Properties of Food Flow Networks.” *PLOS One*, July 10, 2018. https://doi.org/10.1371/journal.pone.0199498.

Lin, X., Q. Dang, and M. Konar, 2014. “A Network Analysis of Food Flows within the United States of America.,” *Environmental Science and Technology* 48: 5439–5447, https://doi.org/doi:10.1021/es500471d.

Lin, X. et al., 2019. “Food Flows between Counties in the United States,” *Environmental Research Letters* 14(8):July 26, 2019. https://doi.org/10.1088/1748-9326/ab29ae

National Research Council, 2015. *A Framework for Assessing Effects of the Food System*. Washington, D.C.: National Academies Press.

Parsons, B. 2007. “The State of Methods and Tools for Social Systems Change,” American Journal of Community Psychology 39(3-34):405-409. https://doi.org/DOI 10.1007/s10464-007-9118-z

Pomponi, P, et al. 2013. “Horizontal Collaboration in Logistics: A Comprehensive Framework,” *Research in Logistics and Production* 3(4): 243–54.

Rosenzweig, C. et al. 2020. “Climate Change Responses Benefit from a Global Food System Approach.” *Nature Food* 1: 94–97.

Tello E., González de Molina M. 2017. Methodological Challenges and General Criteria for Assessing and Designing Local Sustainable Agri-Food Systems: A Socio-Ecological Approach at Landscape Level. In: Fraňková E., Haas W., Singh S. (eds) Socio-Metabolic Perspectives on the Sustainability of Local Food Systems. Human-Environment Interactions, vol 7. Springer, Cham. https://doi.org/10.1007/978-3-319-69236-4_2

UTURN, “Paving the Way for Smarter, Sustainable, and Customer-Driven 3PL Operations via Shared Freight Deliveries in Attica Region.,” (2018), http://www.u-turn-project.eu/pilot-1---athens.html

2C. Conservation practices to minimize flooding and nutrient runoff

2C.1 Conservation Practices to minimize flooding

Author: Bob Micheel

Over the past 15 years, some of the conservation practices most frequently used by county and federal conservation staff across Wisconsin have proven unable to handle increasing runoff resulting from the dramatic upsurge in precipitation amounts and intensity due to climate change. For some practices, the design modifications necessary to meet the changing climate make the practices themselves too expensive to implement. The reality is that we must adapt current conservation practices themselves, to include cost-effective options that are capable of withstanding ever more extreme weather events. The need for adaptation is particularly evident for stream restoration and flood retention structures.

These intense storm events have highlighted critical areas where conservation practice recommendations, practicality, and economics are creating change within state and federal design standards. A majority of Wisconsin conservation practices were designed for the 10-year, 24-hour storm event, but are evolving to consider designs capable of handling 100-year, 24-hour storm events to ensure resiliency in light of climate change. The current parameters/considerations on structural practices are changing, most notably in stream restoration and flood retention structures.

Examples:

- Conservation practice recommendations within the upper reaches of high gradient streams have changed from bank stabilization with hard armoring (i.e., riprap) to shaping/seeding and minimized structure for fish habitat.
- Stream crossings for municipal and private roads that cut across valley floors act as dams during these massive storm events. They have changed stabilization efforts of hard armoring to shaping and seeding immediately (100-200’) below crossings.
- Some areas of the state are adding additional considerations for the structural design of grade stabilization structures (dams) for overtopping during massive flood events. These considerations include adjusting the top of dam elevation to focus water over the placed fill within the structural footprint vs. the natural abutment. Dam overtopping and downstream flood evaluations for stability and liability are essential components to the design.

2C.2. Nutrient runoff and water management challenges

Authors: Kevin Shelley and Sara Walling

Climate trends toward increased rainfall, particularly in winter and spring, as well as more intense and heavy rainfall events throughout the year, cause increasing concern for soil erosion and contamination of surface and groundwater resources with sediment and nutrients from agricultural lands.[1,2,3] Intensive management of annual crops in the absence of site-specific conservation and soil health practices often contributes to localized flooding as well. Strategies are necessary to transition Wisconsin’s agricultural production systems toward greater climate resilience and resulting environmental and economic sustainability.

Public policy and program options may include tax credits, incentive payments and regulation. The expenditure of public funds will require effective accountability measures. But, research and education to enable economically profitable implementation will be necessary, as will increased technical assistance and conservation planning through county land and water conservation agencies. Public-private collaboration to develop value chain certifications for farm products or ecosystems services markets could potentially cover some costs accrued by farmers during transition processes. Agricultural processors, distributors, input suppliers, farm service providers, and others who economically benefit from agricultural production should help bear the costs of needed conservation measures and advocate for their adoption within their supply chains.

Climate sensitive agricultural production system and practices priorities:

Protect soil from wind and water erosion, reduce surface water runoff and increase water infiltration, thereby achieving resilience against impacts of heavy rainfall events as well as drought conditions:

1. Increase the amount of perennial vegetation and cover crops on agricultural land,
2. Include more rotational grazing as part of livestock and cropping system management so less grain (which needs large amounts of N) is required for animal feed, and to achieve solution #1 above,
3. Improve nutrient and manure management practices to better match nutrient application rates and timing with crop nutrient needs,
4. Diversify crop rotations for agro-ecological pest and nutrient management benefits to reduce the need for nitrogen fertilizers and pesticides,
5. Implement comprehensive conservation planning on farms to inventory needs and identify opportunities to improve soil health and minimize soil and nutrient loss through runoff, leaching and erosion. Enable implementation of identified necessary structures and practices.
6. Avoid grassland or natural vegetation conversion to row crop production or development, as well as avoiding conversion of productive agricultural land to development. By increasing perennial vegetation on the landscape, we will move towards increasing soil C sequestration, reducing soil erosion, runoff, and nitrate leaching into groundwater, and increase biodiversity across the landscape. These changes would lead to increased resiliency of our landscapes to extreme weather events, while improving environmental conditions, human health, and agriculture's overall contribution to a changing climate.

References

[1.] Wisconsin Initiative on Climate Change Impacts, 2020. Strategies to improve Wisconsin's climate resilience and readiness: Report to the Governor's Task Force on Climate Change. July 31, 2020.
[2.] Hatfield, J.L. and J.H. Pruege, 2004. Impacts of changing precipitation patterns on water quality. Journal of Soil and Water Conservation. January 2004, 59 (1). https://www.jswconline.org/content/59/1/51.

[3.] Nearing, MA., F.F. Pruski and M.R. O'Neal, 2004. Expected climate change impacts on soil erosion rates: A review. Journal of Soil and Water Conservation. January 2004, 59 (1). https://www.jswconline.org/content/59/1/43.

2C.3. Case study: Flood Resilience in the Coon Creek Watershed

Author: Jackson Parr

In August 2018, severe rainfall throughout southwest Wisconsin resulted in the breach of five dams, the evacuation of hundreds from their homes, and millions of dollars in damage. Specifically, within 24 hours, up to twelve inches of rainfall fell in the Coon Creek watershed. This extreme event is representative of an increasing trend in the frequency of heavy rainfall events in the region (Wright et al. 2020) that is driven by a warming climate.

The agricultural landscape is critical to the region's economy and culture. The Coon Creek watershed was home to the nation's first watershed demonstration project in the 1930s, which employed the Civilian Conservation Corps to implement land use practices such as contour strips, terracing, and grassed waterways to reduce erosion and mitigate flood events. Trimble (2009) found this work with agricultural lands was critical to reducing flood impacts in the region.

Since the watershed demonstration project, some of these conservation practices have been removed due to broad drivers in the agricultural system. Economic pressures have reduced the presence of dairy in the region, which has subsequently resulted in the conversion of some perennial forage land to corn and soy that are more likely to reduce infiltration and increase the potential for runoff and flood events.

As climate change is expected to result in more frequent and severe rainfall in the region, residents and officials are grappling with how to mitigate and adapt to future flood events. Although Monroe County created a Climate Change Task Force, a forthcoming report from the University of Wisconsin-Madison Nelson Institute's Water Resources Management program found that the topic of climate change can be politically volatile in the region. Recognition of the impacts of climate change on precipitation in the region, and the role of agricultural practices to improve infiltration, will be critical to flood resilience in the watershed.

References

Trimble, S. W. (2009). Fluvial processes, morphology and sediment budgets in the Coon Creek Basin, WI, USA, 1975–1993. *Geomorphology*, *108*(1–2), 8–23. https://doi.org/10.1016/j.geomorph.2006.11.015

Wright, D., Li, Z., & Booth, E. (2018). *Using Stochastic Storm Transposition to Update Rainfall Intensity-Duration-Frequency (IDF) Curves for the Coon Creek and West Fork Kickapoo Watersheds*. 30. https://crawford.extension.wisc.edu/files/2020/10/Rainfall-Analysis_UW-Madison-1.pdf

2D. Environmental climate justice: Impacts on Workers, People, Communities

Authors: John Shutske, Jenna Pavela, and Paul Stoy

Climate change directly and indirectly fuel farmer stress and anxiety. This is in part connected to increased volatility in weather patterns, extreme events, and associated impacts. Stress is provoking by altering "sense of place" when one is displaced or when operations are forced to change, as has been documented in agricultural systems worldwide.

Farm workers, including all groups from migrant/immigrant, older workers, and children, face elevated and significant risks associated with working in high heat and/or humidity. This includes heat stress, heat exhaustion, heat stroke, impacts on kidneys and other critical organs. Heat and humidity also amplify other hazards like injury risk and adverse impacts on pregnancy and birth. Continued change amplifies exposure to new pathogens as a result in changes in vector populations including mosquitoes, ticks, rodents, and more.

There is already significant documented migration out of Central America among people who are currently involved in farming and agriculture into the U.S. This will create additional pressures on the need for sound immigration and labor policy, likely having an impact on Wisconsin farmers, especially as we continue to see labor challenges and increased opportunities to automate.

For consumers (and with significant worker implications) there will be amplified risks associated with food safety. This includes increased exposure to new and existing zoonotic diseases, mycotoxins, and food safety/pathogen implications associated with flooded areas, standing water, and other adverse storage and field conditions (grain stored in bins in humid conditions is difficult to manage and prone to mold growth, as one example).

Climate related pressures and stresses to production systems often result in lower production and therefore less ability of a given geographic area or region to support a thriving local economy, leading to deleterious economic impacts and out-migration.

Extreme weather impacts day-to-day productivity of individual workers and entire workforces, leading to measurably greater labor needs (numbers of people) and/or increased investment in automation - by some accounts also increasing cost of production and/or food prices.

Increased pest and disease pressures (including insects, weeds, pathogens) from changes in climate and the immediate environment leads to additional worker and community exposures to pesticides and, in the livestock sector, antimicrobials.

There are significant issues associated with equity, disparity among groups (migrant/immigrant; smaller producers; those with less access to education, capital or other resources), which makes adaptation more difficult and provides for fewer options to adapt.

References

Applebaum, K. M., Graham, J., Gray, G. M., LaPuma, P., McCormick, S. A., Northcross, A., & Perry, M. J. (2016). An Overview of Occupational Risks From Climate Change. *Current Environmental Health Reports*, *3*(1), 13–22. https://doi.org/10.1007/s40572-016-0081-4

Boxall Alistair B.A., Hardy Anthony, Beulke Sabine, Boucard Tatiana, Burgin Laura, Falloon Peter D., Haygarth Philip M., Hutchinson Thomas, Kovats R. Sari, Leonardi Giovanni, Levy Leonard S., Nichols Gordon, Parsons Simon A., Potts Laura, Stone David, Topp Edward, Turley David B., Walsh Kerry, Wellington Elizabeth M.H., & Williams Richard J. (2009). Impacts of Climate Change on Indirect Human Exposure to Pathogens and Chemicals from Agriculture. *Environmental Health Perspectives*, *117*(4), 508–514. https://doi.org/10.1289/ehp.0800084

Burzyński, M., Deuster, C., Docquier, F., & De Melo, J. (2019). *Climate Change, Inequality, and Human Migration*.

Cattaneo, C., Beine, M., Fröhlich, C. J., Kniveton, D., Martinez-Zarzoso, I., Mastrorillo, M., Millock, K., Piguet, E., & Schraven, B. (2019). Human migration in the era of climate change. *Review of Environmental Economics and Policy*, *13*(2), 189–206.

de Lima, C. Z., Buzan, J. R., Moore, F. C., Baldos, U. L. C., Huber, M., & Hertel, T. W. (2021). Heat stress on agricultural workers exacerbates crop impacts of climate change. *Environmental Research Letters*, *16*(4), 044020. https://doi.org/10.1088/1748-9326/abeb9f

Ellis, N. R., & Albrecht, G. A. (2017). Climate change threats to family farmers' sense of place and mental wellbeing: A case study from the Western Australian Wheatbelt. *Social Science & Medicine*, *175*, 161–168.

Fenske, R. A., & Pinkerton, K. E. (2020). *Climate Change and the Amplification of Agricultural Worker Health Risks*. Taylor & Francis.

Greig, B., Nuthall, P., & Old, K. (2020). An Analysis of Farmers' Human Characteristics as Drivers of Their Anxiety. *Journal of Agromedicine*, *25*(1), 135–146.

Hansen, A., Bi, L., Saniotis, A., & Nitschke, M. (2013). Vulnerability to extreme heat and climate change: Is ethnicity a factor? *Global Health Action*, *6*(1), 21364.

Kearney, G. D., & Garzon, L. (2020). Calor extremo: On the frontlines of climate change with North Carolina farmworkers. *North Carolina Medical Journal*, *81*(5), 311–314.

Kiefer, M., Rodríguez-Guzmán, J., Watson, J., van Wendel de Joode, B., Mergler, D., & da Silva, A. S. (2016). Worker health and safety and climate change in the Americas: Issues and research needs. *Revista Panamericana de Salud Pública*, *40*, 192–197.

Konkle, Darlene. Zoom Call. March 16, 2021.

Levy, B. S., & Roelofs, C. (2019). Impacts of climate change on workers' health and safety. In *Oxford Research Encyclopedia of Global Public Health*.

Lunner Kolstrup, C., Kallioniemi, M., Lundqvist, P., Kymäläinen, H.-R., Stallones, L., & Brumby, S. (2013). International Perspectives on Psychosocial Working Conditions, Mental Health, and Stress of Dairy Farm Operators. *Journal of Agromedicine*, *18*(3), 244–255. https://doi.org/10.1080/1059924X.2013.796903

McLaughlin, J., & Weiler, A. M. (2017). Migrant agricultural workers in local and global contexts: Toward a better life? *Journal of Agrarian Change*, *17*(3), 630–638.

Rudolphi, J. (2020). *Diversity of mental health issues in agriculture*. Taylor & Francis.

Semple, K. (2019). Central American farmers head to the US, fleeing climate change. *The New York Times*.

Shayegh, S. (2017). Outward migration may alter population dynamics and income inequality. *Nature Climate Change*, *7*(11), 828–832.

Smith, D. J., Pius, L. M., Plantinga, L. C., Thompson, L. M., Mac, V. V. T., & Hertzberg, V. S. (2021). Heat Stress and Kidney Function in Farmworkers in the US: A Scoping Review. *Journal of Agromedicine*.

Vanos, J., Moyce, S., Lemke, B., & Kjellstrom, T. (2021). Extreme Heat Exposure and Occupational Health in a Changing Climate. *Extreme Events and Climate Change: A Multidisciplinary Approach*, 147–166.

Wattiaux, Michel. Zoom Call. March 23, 2021.

2E. Summary of potential strategies and solutions to address a changing climate and impacts on agriculture.

Here, a summary of key climate change issues identified for agriculture is presented, along with the key impacts and strategies and solutions.

Issue	Impact	Strategy/Solution
Wetter winters and springs	* Waterlogged soils * Delays in planting * More nutrient and soil runoff to surface water * More flooded fields	* Plant more cover crops * No-till farming / retain crop residue * Shift to shorter-season hybrids * Manure digesters/storage units * Manure injection * Tile drainage * Riparian buffers/CREP
Increased rainfall and frequency of extreme rainfall events	* More nutrient runoff * More soil erosion * More groundwater flooding and flooded crop fields * Delayed or more challenging fall harvest of crops	*Increase infiltration rates on ag fields - Tile drainage - Cover crops - more perennial grass systems - establish grassed waterways - no-till/reduced tillage - Continuous cover systems * Shoreland/floodplain protection

		- Wetland protection and restoration - Riparian buffers/CREP installations/streambank protection *Reduce nutrient losses to ground and surface water - Increase precision agriculture practices - Increase soil organic matter
Extreme heat during summer and expanding growing seasons	* Increased animal heat stress * Decreased milk production * Decreased crop production * Increased irrigation demand	* Improve cooling capacity for animals * Adaptation through use of longer-season crop hybrids, use of alternative crop types in rotations/across crop system * Improve crop breeding/genetics to increase water/nutrient use efficiency - Increase soil organic matter (cover crops, no till, solid manure) to increase water holding capacity and reduce drought symptoms
Warming winters	* Cranberry industry – loss of ice * Increased pest overwintering * More runoff on frozen ground * More freeze/thaw cycles in soils	* Switch to different crop types * Increase capacity to handle/store manure * Increase use of solid manure storage systems vs. liquid based storage * Increase use of cover crops to provide year-long living roots/cover * Adaptation through use of longer-season crop hybrids, use of alternative crop types in rotations/across crop system, Improve crop breeding/genetics to increase pest/disease tolerance
Warming springs	* Increased likelihood of “false springs”: early blooming of fruit crops like cherry & apple that become susceptible to freeze	* Increased capacity for protecting crops during cold nights (probably limited) Increase use of solid manure storage systems vs. liquid based storage

Appendix A

WICCI Research Brief 1.0

Sharing research-based solutions to improve Wisconsin's climate resilience and readiness.

Title: Decreasing Wisconsin's agricultural contributions to climate change and improving soil and water resources through improving agricultural resiliency to climate change impacts

Authors: Chris Kucharik (UW-Madison), Sara Walling (DATCP)

Executive Summary: One of the most pressing concerns with Wisconsin agriculture and climate change is that due to the dominance of just a few crops across the landscape comes a heavy reliance on nitrogen fertilizer or manure application to sustain high production levels. This leads to soil N_2O emissions and continuous soil tillage operations causes losses of soil organic matter in the form of CO_2 release to the atmosphere. Increasing annual average rainfall and a trend towards more frequent heavy rainfall events is also causing increased loss of nutrients from farming systems to our surface waterways and groundwater and increased soil erosion rates that decrease soil carbon storage, crop productivity and also increase surface water degradation.

Wisconsin needs to adopt land-use and land management strategies that decrease agriculture's greenhouse gas (GHG) emissions, promote soil carbon sequestration, decrease the use of less productive, more sensitive land for agricultural production that require higher inputs of fertilizers, and increase agriculture's resiliency to the climate change impacts we face. Solutions and strategies must be economically viable or incentivized for producers while providing protection from future climate change impacts and potential future regulation of agrochemicals or land management practices. Some solutions may include:

(1) increasing the acreage of perennial grasses and cover crops/living cover on agricultural land,

(2) including more rotational grazing as part of livestock and cropping systems management so less grain (which needs large amounts of N) is required for animal feed and to achieve solution #1 above,

(3) improving nutrient and manure management practices to reduce liquid manure storage and better align nutrient application rates with plant nutrient need, and

(4) avoiding grassland or natural vegetation conversion to row crop production or development, as well as avoiding conversion of productive agricultural land to development. Increasing perennial vegetation across agricultural land will increase soil C sequestration, reduce soil erosion, runoff, and nitrate leaching into groundwater, increase biodiversity, and make our food-energy-water systems more resilient to a changing climate.

Climate Impacts:

☒ More hot weather (many more 90- or 100-degree days, with many more muggy nights)

☒ Less extreme cold (fewer nights below 0 degrees)

☒ More frequent occurrences of snow melt with more mild winter days

☒ Longer growing season (earlier last frost in spring and later first frost in fall)

☒ Wetter overall climate, especially during winter and spring

☒ More intense and frequent heavy rainfalls

☒ Winter precipitation increasingly rain and possibly freezing rain but less snowfall.

☒ More summer droughts

Issue:

Agriculture is a significant contributor of greenhouse gases to the Earth's atmosphere and agrochemicals to water resources, and is directly impacted by a changing climate and increasing weather variability. One of the most pressing concerns with commodity agriculture today (e.g. corn, wheat) and other specialty crops (e.g. potato and vegetable production) in Wisconsin is a reliance on inorganic nitrogen fertilizer or liquid manure applications to sustain high production levels.

Other impacts of these type of management systems include reduced diversity in crop rotations and increased animal confinement operations compared to grazing systems. This leads to increased N_2O and CH_4 emissions and a continuation of soil tillage management practices can cause losses of soil organic matter and CO_2 from the soil to the atmosphere. Increasing annual average rainfall and a trend towards an increasing frequency of heavy rainfall events is also causing more loss of soil and nutrients from farming systems to our surface waterways (often phosphorus) and groundwater (nitrate). Unfortunately, current recommended nutrient application rate recommendations (fertilizer amount) put forth by UW Division of Extension (e.g. Laboski and Peters 2012) were not designed to protect water quality or eliminate N_2O emissions (associated with N fertilizer use) to the atmosphere.

Why is this a concern?

First, we know that soil health is directly related to the amount of soil carbon (organic matter) contained. Previous land-use change across a large portion of Wisconsin – from tallgrass prairie and oak savanna/grassland – to row crop agriculture over the last 200 years has contributed to a 30-60% loss in soil carbon (Kucharik et al. 2001; Kucharik and Brye 2003). Also increased use of tillage practices in traditional row crop production systems further diminished the ability of agricultural soils to store carbon.

Second, due to the increasing usage of nitrogen fertilizers since the 1950s, nitrate concentrations in groundwater have risen to a point that a large fraction of private wells are now above the EPA 10ppm safe drinking water standard (WI Groundwater Coordinating Council, 2019). Thus, land use conversion from natural systems to managed ones have led to increased GHG gas emissions as well as increased agrochemicals in our surface and drinking water. These results are based on direct observations and collection of soil and water samples across Wisconsin.

Strategy or solution:

We need to adopt strategies in agriculture whereby we decrease the amount of GHG emissions promote soil C sequestration, and decrease the amount of land in production that requires high inputs of fertilizers. The easiest solutions to accomplish this are to (1) increase the amount of perennial vegetation and cover crops on agricultural land, (2) include more rotational grazing as part of livestock and cropping system management so less grain (which needs large amounts of N) is required for animal feed, and to achieve solution #1 above, (3) improve nutrient and manure management practices to reduce liquid manure storage and better align nutrient application rates with plant nutrient need, and (4) avoid grassland or natural vegetation conversion to row crop production or development, as well as avoiding conversion of productive agricultural land to development. By increasing perennial vegetation on the landscape, we will move towards increasing soil C sequestration, reducing soil erosion, runoff, and nitrate leaching into groundwater, and increase biodiversity across the landscape. These changes would lead to increased resiliency of our landscapes to extreme weather events, while improving environmental conditions, human health, and agriculture's overall contribution to a changing climate.

References or recommended sources:

Kucharik, C.J., J.A. Roth, and R.T. Nabielski (2003). Statistical assessment of a paired-site approach for verification of C and N sequestration on Wisconsin Conservation Reserve Program (CRP) land. Journal of Soil and Water Conservation 58, 58-67.

Kucharik, C.J., K.R. Brye, J.M. Norman, J.A. Foley, S.T. Gower, and L.G. Bundy (2001). Measurements and modeling of carbon and nitrogen cycling in agroecosystems of southern Wisconsin: Potential for SOC sequestration during the next 50 years. Ecosystems 4, 237-258.

Laboski, C. and J. Peters. 2012. Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin. University of Wisconsin Extension publication A2809. 92pp.

Wisconsin Groundwater Coordinating Council. 2019. Nitrate, Wisconsin Groundwater Coordinating Council Report to the legislature. https://dnr.wi.gov/topic/Groundwater/documents/GCC/gwQuality/Nitrate.pdf. Last accessed May 14, 2020.