Agriculture, transportation and climate change: Considering the future of agricultural freight transport in the Upper Mississippi River Valley

November 2015

The World Economic Forum (2015) rates food crises, extreme weather and failure of infrastructure as top global risks in 2015. Around the world, regions are contending with extreme weather, including drought, flooding and changes in growing seasons. These extremes affect crops and pests, and may disrupt agriculture and its supply chains, especially in the second half of this century. This paper presents an example of how transportation of agricultural products in the Upper Mississippi River Valley region of the United States may be impacted by, and respond to, a changing climate.

Global markets depend on exports produced in the Upper Mississippi River Valley, many of which are shipped down the Mississippi River. The Mississippi is one of the world's major rivers, measuring 2,340 miles from its origin in Minnesota to its mouth in the Gulf of Mexico (Kammerer 1990).The Upper Mississippi River Valley runs along either side of the Mississippi River and includes most of Minnesota, Wisconsin, Iowa, Illinois and Missouri. St. Louis is the southernmost major river port for this fertile agricultural region, and the valley ends where the Mississippi and Ohio rivers meet in Southern Illinois. Agriculture in the Mississippi River Valley is part of the global food trade network; the flow of food from the Illinois-centered Corn Belt to Louisiana ports is the largest link, in terms of trade volume, between U.S. agricultural production and international markets (Lin et al. 2014).

Because of its important role in food production and transport, weather extremes in the Upper Mississippi River Valley are of special concern. Extreme weather affects agricultural production, transportation and markets, both directly through impacts on waterways and highways, and indirectly through changes to regional, national and international agricultural production patterns. In the Upper Mississippi River Valley, erratic spring and fall freezing, as well as fluctuating water levels due to drought and flooding, may interrupt barge transportation. This may, in turn, increase reliance on truck freight and place greater demands on road infrastructure. Altered growing seasons are likely to affect both the volume and location of grain production, with major grain-producing regions predicted to shift north and west. These changes may affect freight logistics for grain. Adapting to such dynamic circumstances requires flexible, responsive protocols and relationships across the food supply chain—from farms through grain elevators, trucks and barges, brokers, buyers, regulators, and global markets.

A team of University of Wisconsin-Madison researchers took a closer look at how climate change might impact agricultural production and transportation in the Upper Mississippi River Valley. The researchers surveyed current literature and interviewed 11 people across the supply chain, from private industry, state and local government, and agricultural and nonprofit organizations in this region. Their work shows that both public and private sector adaptations to unpredictable weather and markets, including regional crop and supply chain diversification, can add resilience to our food system.

Climate change in the Upper Mississippi River Valley

Changing weather conditions in the Upper Mississippi River Valley are already impacting agriculture. To date, warmer temperatures are credited with generally increased yields in the Upper Midwest. However, more volatile spring weather, increased hail incidents, heavier rains and snows, and longer dry stretches during the summer are examples of emerging weather trends that are challenging farmers in this region and adding uncertainty to an already risky profession. The Intergovernmental Panel on Climate Change (IPCC) projects increasingly unpredictable and challenging weather patterns by mid-century (McCarl 2015a&b). The Wisconsin Institute for Climate Change Research (WICCI) projects that, by 2050, winters will be significantly warmer and heavy rain events more frequent (see Figs. 1 and 2 on page 3).

Agricultural economist Bruce McCarl (McCarl 2015a&b), who serves on the IPCC, categorizes three types of adaptation to the changing climate. "Natural adaptation" involves individual species reacting to changing weather at an ecosystem level. "Autonomous adaptation" is businesses and other decision makers voluntarily acting to adapt to our changing climate. "Planned adaptation" is intervention by governments to address public needs that are unlikely to be met through autonomous responses.

Natural adaptation

Plants and animals may adapt to the changing climate in ways that negatively impact agriculture. Warming could shift favorable growing conditions for invasive weeds to the north, and climate change is expected to increase the frequency of weeds, pests and diseases. This may cause new headaches for growers (Blanc and Reilly 2015, Rose 2015).

Globally, the IPCC estimates that temperature increases could be responsible for 30 to 82 percent declines in corn and soybean yields by the end of the century, with more severe declines expected in tropical than in temperate regions (Blanc and Reilly 2015). There is a majority consensus that yields will fall from the 2030s onward (Challinor et al. 2014). Extreme weather may impact plant germination, bloom, bud set and ripening, as well as pollination by insects. Seasonal temperature volatility and extreme rain and snow events are stressful for perennial crops. Pasture quality decline due to heat, drought or other factors leads to reduced stocking rates (McCarl 2015b).

Heat stress in livestock resulting from climate change could result in lost production. Heat stress occurs in animals when rising temperatures leave them unable to maintain a normal body temperature without physiological and metabolic changes. Short-term adaptation to heat stress can limit livestock reproductive capacity or reduce milk volume, and dairy cows are particularly susceptible (Key et al. 2014).

Autonomous adaptation

Farmers face increasing uncertainty due to weather volatility. In years when weather is good, crop production may be high but prices low; when weather is poor, crop production may decline yet prices may rise. These highs and lows are expected to intensify as weather grows more extreme, and they could have ripple effects on distant markets. Severe droughts in North America, Africa and Russia have impacted global grain supply chains.

Globally, population growth and an expanding middle class are increasing food and fuel demand. Domestically, in 2015, 5.25 billion bushels of corn were produced for fuel use, compared to 5.275 billion bushels for feed and residual use and 1.38 billion bushels for other food, seed and industrial use (USDA ERS 2015). About 72 percent of U.S. corn exports went to five Organization for Economic Cooperation and Development (OECD) nations in 2009: Japan, Mexico, South Korea, Taiwan and Egypt. That year, about nine percent of U.S. corn exports went to 70 nations designated by the United Nations Food and Agriculture Organization (FAO) as Low-Income Food Deficient (Olmstead 2011).

Several interviewees commented that the increased use of biofuels to reduce reliance on petroleum, especially ethanol made from corn, may contribute to uncertainty and shortages in agricultural markets (Blanc and Reilly 2015, Jokinen et al. 2015).

The interviews revealed concerns that increasingly volatile weather will intensify farming challenges across the Upper Mississippi River Valley, for all crops. Farmers are able to manage some of the risk, both to their crops and their soil, resulting from uncertain weather.

Examples of risk management strategies for farmers suggested by the interviewees include:

- Investing in capital-intensive strategies such as irrigation systems for both annual and perennial crops
- Mitigating risk through genetic solutions such as drought-and heat-tolerant corn hybrids and GMO traits to simplify pest management, even though specialized seed is costly
- Growing more soybeans and alfalfa, as these crops tolerate dry and wet conditions better than corn
- Employing farm management strategies such as cover cropping, prairie strips, no-till, contour planting and grassed waterways to reduce soil erosion, nutrient runoff and soil moisture depletion, which are exacerbated by heavy rain

Extreme rainfall events due to climate change may result in a dramatic increase in soil erosion, especially from highly erodible land and fields without vegetative cover. In the Upper Mississippi River Valley, the sloping terrain of the four-state Driftless Region is particularly vulnerable to soil erosion (see Fig. 3 on page 5). In addition to the soil conservation measures mentioned above, diversifying annual crop production with perennial crops protects soil from erosion and increases carbon storage to reduce greenhouse gas (GHG) emissions (Lewandrowski and Zook 2015). Perennials can provide year-round ground cover and roots to hold soil and nutrients in place. A five-year study of 12 agricultural watersheds in central Iowa found that strategically planting 10 percent of row crop fields to perennial prairie grass strips reduced runoff water nitrogen by 84 percent and phosphorus by 89 percent, respectively (Helmers et al. 2012, Zhou et al. 2014). However, farmers face increased economic risk with perennial crops. Incorporating perennial crops into a grain or livestock operation involves management risks associated with adopting new production practices and more complex farming systems. Establishing high-value perennial crops such as tree fruit and nuts requires a substantial capital investment, and may involve the need to create processing infrastructure.

Crop diversification is proposed as a strategy to both adapt to a changing climate and mitigate GHG emissions (Aguilar et al. 2015, Blanc and Reilly 2015, Lewandrowski and Zook 2015, Lengnick 2015, Rotter 2013), as well as protect against market shocks (Aguilar et al. 2015, Blanc and Reilly 2015). Converting row crop acres to perennial pasture for livestock reduces soil erosion due to heavy rainfall. In annual cropping systems, cover cropping protects soil, and incorporating perennial crops into these systems can also prevent erosion.

Supply chain disruptions could exacerbate grain shortages resulting from extreme weather events. In the domestic livestock market, the regular flow of feed from grain farms to livestock operations is critical. One of the interviewees stated

Figure 1. Modeled change in average temperature (°C) by season, 1961-2000 to 2045-2065

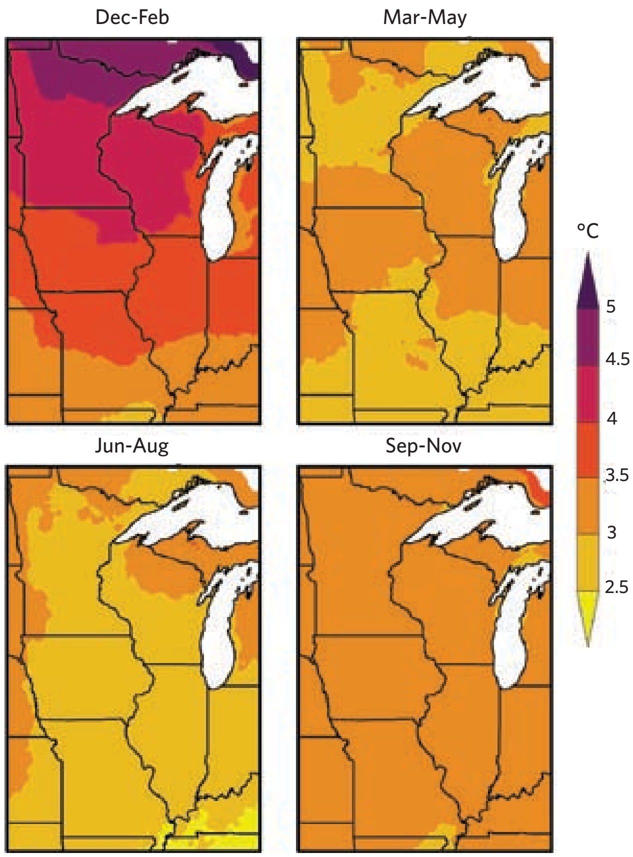
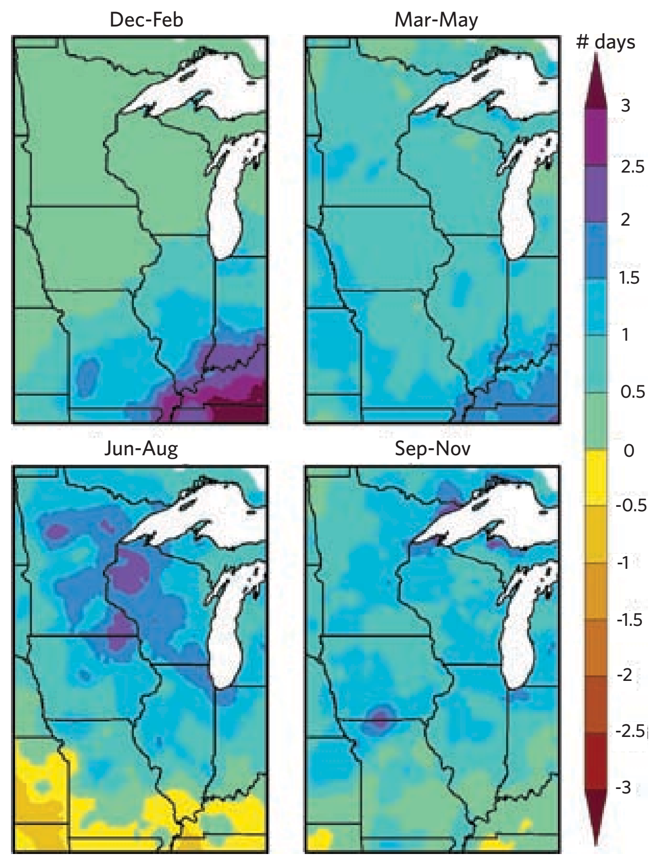


Figure 2. Modeled change in number of days/decade with >50 mm (2 in.) of precip. by season, 1961-2000 to 2045-2065



Source: These regional precipitation and temperature maps are based on daily statistically downscaled climate projections (WICCI 2011, Notaro et al. 2014). Researchers took observed weather data from 1950-2009, and then projected future conditions using climate models developed by the World Climate Research Programme for the Intergovernmental Panel on Climate Change. The projections illustrated by the maps are compiled from thirteen climate models including three from the U.S., two from Canada, and others from Japan, Germany, South Korea, France and Australia.

By 2050, these projections show that winters will be significantly warmer — as much as an average of 5°C, or 9°F degrees warmer. This will impact snow cover, frozen ground, and the occurrence of ice storms rather than snow, and rain rather than ice. The Upper Mississippi River Valley is expected to become more like the Lower Mississippi River Valley. Seasonal snow melt in mid-spring will likely change to recurring snow melt throughout the winter season, so, for example, Wisconsin's weather will be more like what Missouri is experiencing now. Spring and fall are projected to be considerably warmer — as much as 3.5°C or 6.5°F.

An increase in the number of days per decade when it rains two inches (50 mm) or more is also of concern. For example, two-inch storms currently occur about six to eight days per decade in the summer (Jun-Aug). In the future, these storms will increase by about 1.5 to 2 days per decade during summer. Although the absolute increase is smaller in spring and fall, the relative increase is larger: in spring the current frequency is about two days per decade increasing by about one day per decade. In fall, the current frequency is three days per decade increasing by one to 1.5 days per decade. These heavy spring and fall precipitation events occur when soil may be unprotected by plant cover in annual cropping systems, and therefore erosion might be of special concern.

that livestock farmers are especially vulnerable to feed supply disruptions and cost increases due to extreme weather. This interviewee also said that domestic supply chain disruption is already occurring in coastal states where farmers may not raise feed for their own animals, due to high land prices. This person thought that population migration from coastal areas affected by climate change leads to an increase in inland land prices. Grain processors are looking to geographically diversify their suppliers so that if extreme weather impacts crop production in one region, they will be able to source ingredients elsewhere (Bjerga 2012). This, in turn, increases transportation infrastructure demands.

Agricultural freight could travel in more fuel-efficient, cost-effective ways that also reduce GHG emissions (Ala-Harja and Helo 2015). Expanding opportunities to move more grain via rail and barge, as well as rethinking truck transportation logistics in urban and peri-urban areas, are ways to reduce emissions. Another is to take advantage of engineering innovations such as aerodynamic trailers and alternative fuels for long- and short-haul freight movements. Bringing food production and markets closer together while increasing the distribution efficiencies of local markets is another approach to reducing emissions. Regionalizing food supply chains through integrated agricultural systems may reduce GHG emissions by decreasing the number of vehicles and amount of fuel required for food distribution (Bosona and Gebresenbet 2011, Jokinen et al. 2015). Reducing the need to ship food long distances will reduce emissions and improve food system resilience.

Planned adaptation

Government at all levels is being called upon to identify and support solutions to volatility in natural and human systems, including crop production and agricultural market dynamics, resulting from a changing climate. Supply chain disruptions due to extreme weather events, and pest and disease outbreaks, may become more common. Processors and end users may source food and feed grains differently, and from multiple sources, to adapt to these disruptions. Government responses that reduce immediate risks to people and economies, while supporting long-term private sector adaptation, are key.

Federal farm policy reduces the risk of growing some crops. Before the 2014 Farm Bill, federal programs made direct subsidy payments to farmers who grew corn, soybeans, wheat and other major commodity crops. In that legislation, subsidized crop insurance against price loss and disasters replaced direct payments, and new risk management instruments emerged to support more diversified farming practices.

From 1985 to 2002, farmers wanting to participate in programs subsidizing commodity crops were required to enroll in federal conservation programs established to reduce soil erosion and improve water quality. The resulting enrollment of land in the Conservation Reserve Program (CRP) and other resource conservation programs led to a measurable decline in soil loss.

The 2002 Farm Bill decoupled commodity support programs from conservation programs. One interviewee noted that commodity prices spiked shortly after this. This interviewee said that farmers responded to the price spike by pulling their land out of programs like CRP and replanting with annual crops, as CRP rental payments were less than market rates for renting crop land, particularly as corn prices rose with growing corn ethanol markets.

Nationally, soil erosion rates for cropland fell 43 percent from 1982 to 2007. However, the most significant declines were seen prior to 1997 (USDA NRCS 2010). Several interviewees suggested that some sub-regions saw a rise in soil erosion after income support and conservation programs were decoupled in 2002. Data from the USDA Natural Resources Conservation Service supports this observation. From 2007 to 2012, CRP acreage across the nation declined more than 25 percent. In the Upper Mississippi River Valley, Wisconsin and Missouri showed the greatest drop, with 35 percent fewer acres enrolled in CRP by 2012. In that same period, soil erosion began to increase. Nationally, soil erosion caused by water returned to 1997 levels by 2012. In the Upper Mississippi River Valley, most states in the region reported increased soil loss in 2012, ranging from 4.01 tons/acre in Illinois to 6.06 tons/acre in Iowa. Only Minnesota reported less than two tons/acre soil loss that year (USDA NRCS 2015).

The 2014 Farm Bill again linked conservation program participation to insurance premium subsidies for highly erodible lands and wetlands, while reducing overall funding for conservation programs (NSAC 2014a). Conservation compliance is assessed based on the government's erodibility index. This index averages rainfall and other criteria over the past 30 years. Useful as it is, past weather data masks current trends toward more erratic and heavy rainfall events.

This farm bill includes provisions supporting on-farm diversification, such as Whole Farm Revenue Insurance and planting flexibility up to 35 percent of base acres (NSAC 2014b). Supporting regional agricultural diversity both in the U.S. and abroad is critical to maintaining flexibility in food provisioning. Globally, small- to mid-scale farmers are increasingly vulnerable to risks associated with climate change and become targets of financial speculation that work against diversification (Isakson 2015).

Federal and state transportation policies guide public investment in surface transportation infrastructure. U.S., state and local transportation infrastructure is in need of repair and rejuvenation to meet present agricultural transportation needs. The federal gas tax, which funds repairs to the nation's transportation infrastructure, has not increased for over 20 years. The federal Department of Transportation is predicting an annual shortfall of $12 billion in the Transportation Trust

Fund (U.S. DOT 2015). Understanding agricultural needs now and in the future may help prioritize public investment in transportation infrastructure.

Interviewees often mentioned rail as a cost effective and fuel efficient alternative to truck and barge transportation (Tolliver et al. 2013), but rail introduces more complexity into negotiations across the supply chain. Freight rail is privately owned and operated, and requires private sector, rather than public sector, investment. Agricultural products are weak competitors with other products, such as petroleum, for rail access. Furthermore, there are historic conflicts between rail and other transportation modes.

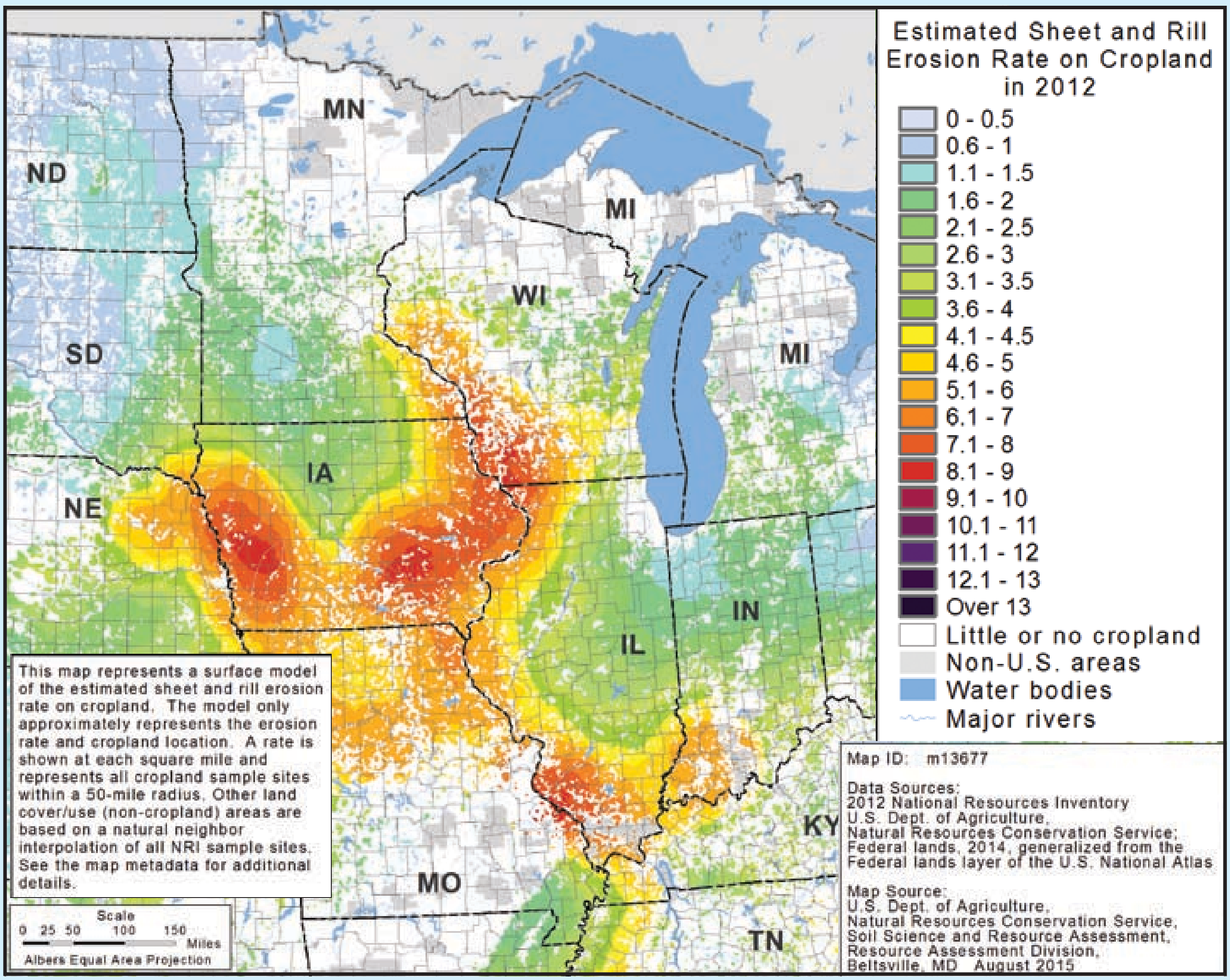
Impacts of climate change on agricultural supply chains

Direct impacts

Predictions of the direct impact of climate change on agricultural transportation in the U.S. differ based on assumptions and variables such as the length of the shipping season on the Mississippi River and Great Lakes, water levels in the Great Lakes, shipping cost comparisons between different trade modes and routes, and grain production in other exporting countries (Attavanich et al. 2013). In 2013, 65 percent of corn exports went through the Mississippi Gulf Port (Denicoff et al. 2014).

Figure 3. Estimated sheet and rill erosion rates on cropland, 2012

Tons per acre, per year



Source: USDA NRCS 2015.

Sheet and rill erosion involves the washing away of soil through rainfall and runoff. There is some overlap between areas currently experiencing high rates of sheet and rill erosion, and areas predicted to experience more extreme rainfall in the future (see Fig. 2). Prioritizing soil conservation efforts in these areas may help protect this natural resource and future agricultural production.

From farm fields to terminal markets, U.S. agricultural freight moves primarily by truck (Blanton 2015). In the Upper Mississippi River Valley, grain for export to markets via Atlantic shipping is trucked to barges that travel down the Mississippi River. Grain destined for Asian markets and ethanol heading to West Coast refineries travels via rail. In 2013, about 45 percent of U.S. grain destined for export was moved by barge, 35 percent by rail and 20 percent by truck to outgoing ports (Sparger and Marathon 2015).

Changes in precipitation, temperature and extreme weather events may impair transportation and supply chain infrastructure. Heavy rainfall events leading to flooding are expected to continue to increase in frequency (Fig. 2). Floods can interrupt river traffic and damage navigation infrastructure, and they can likewise close and damage roads. In the U.S, rural roads are increasingly in poor repair. One interviewee noted that as farms have grown larger and livestock more concentrated, agricultural machinery and vehicles have become too heavy for rural roads as originally engineered. Another interviewee observed that rural road washouts are increasingly common as heavy rainfall pummels under-maintained roads. Moreover, all roads are compromised by climate extremes such as heat, moisture, and freezing and thawing, and require more maintenance than budgets allow (U.S. DOT 2015).

Barge traffic may be disrupted by extreme weather events, especially when early ice ends a barge season. While rising temperatures are projected to reduce ice cover duration overall (Attavanich et al. 2013 and Fig. 1), spring and fall variations are problematic. Warmer temperatures often extend the navigation season. However, interviewees noted that navigation, like the growing season, closes at the first freeze, even if temperatures warm soon afterward.

Because water levels and spring and fall ice patterns may impact barge traffic, **agricultural truck freight may become more important in the Upper Mississippi River Valley** (Attavanich et al. 2013). When it comes to freight transportation for agriculture and other industries, medium and heavy-duty trucks produce the most greenhouse gas emissions (U.S. EPA 2013). The transportation sector is the second-biggest source of GHG emissions in the United States, accounting for a third of CO_2 emitted through the burning of fossil fuel in 2011 (U.S. Department of State 2014).

Indirect impacts

Quantitative models linking climate change, agriculture and food markets are increasingly sophisticated, but remain limited by issues of scale and complexity (Antle 2015, Attavanich et al. 2013, Fischer 2005, Rotter et al. 2013). Models predicting the impacts of climate change on agriculture show that grain production may relocate, likely continuing to shift northward as it has since the middle of the last century (McCarl 2015a&b). While earlier yield models assumed that increased CO_2 would stimulate plant growth, more recent research suggests that weather-related changes that negatively impact plant productivity and decrease system diversity result in declining yields within a decade or less (Zhuoting 2012). These, and other, factors will alter demands on the transportation infrastructure for grain.

The global market for commodity crops and national markets for animal feed and biofuels are changing, sometimes rapidly. **These changes will influence the volume of commodity crops produced, where they are produced, and preferred freight transportation options** (Blanc and Reilly, 2015; McCarl 2015a&b; Paloviita and Jarvela 2015).

Markets drive farmers' production decisions. However, **extreme weather events coupled with changes in rainfall and rising temperatures may reduce yields and shift cropping patterns northward** (e.g., Attavanich et al. 2013, Blanc and Reilly 2015, Zhuoting 2012).

Crop and supply chain diversification at the regional level has the potential to add resilience to our food system in the face of unpredictable weather and markets (Aguilar et al. 2015, Blanc and Reilly 2015, Lengnick 2015, Lewandrowski and Zook 2015, Rotter et al. 2013). Autonomous and planned adaptation to climate change can enhance resilience and food security by fostering this kind of diversity.

Stability through resilience

A growing world population, urbanization and a burgeoning middle class demand more grain (World Economic Forum 2015). In coming years, however, there is potential for unpredictable and extreme weather to disrupt supply from key grain producing regions (Attavanich et al. 2013). Agricultural regions worldwide are already contending with weather extremes and market upsets. Global food security depends on the resilience of farms in every region around the world. In the near term, farmers in the Upper Mississippi River Valley region will continue to export dairy, grains and specialty crops, while also contending with extreme weather. Increased volatility in natural systems may decrease market stability and intensify pressure on already fragile transportation systems and supply chains. As it stands, truck transportation is expected to continue to provide the majority of agricultural freight movement, even though GHG emissions from trucks are of concern.

Policies—both administrative and legislative—that support crop diversification as a public good may increase food system resilience but decrease commodity crop production. Farmers in the Upper Mississippi River Valley who integrate their production of commodity grain with fruit and vegetable production or perennial pastures for livestock may sell less commodity grain. While these market shifts may enhance regional and environmental resilience, they could reduce the amount of grain available for international trade. Targeting public investment to meet changing transportation and infrastructure needs for regional food systems is recommended. This will entail support for rural and urban road infrastructure, attention to freight optimization, and investment in reorganizing how food flows within and between regions and countries.

Public policy has an opportunity to address the underlying causes of extreme weather and support adaptation responses, such as crop and livestock diversification and efficient water use, while buffering immediate risks to farmers and supply chains. Overemphasizing the short term or failing to anticipate consequences may lead to maladaptation, not to mention dedicating resources to programs and plans that may ultimately fail. Policies that encourage the private sector to adapt agricultural and supply chain systems to a changing climate may be coupled with policies that mitigate GHG emissions. Organizations across the global supply chain benefit from working together to plan for uncertain harvests and spatial shifts in food production, while adapting to extreme weather through diversified regional food systems, environmental conservation and systemic transformation of food supply chains.

References

Aguilar, J; Gramig, GG; Hendrickson, JR; Archer, DW; Forcella, F; Liebig, MA. 2015. "Crop Species Diversity Changes in the United States:1978–2012." *PLoS ONE* 10(8): e0136580.doi:10.1371/journal.pone.0136580. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0136580; accessed 10/12/2015.

Ala-Harja, H; Helo, P. 2015. "Green supply chain decisions: Case-based performance analysis from the food industry." *Journal of Transportation Research Part E*, 69C: 97-107. http://dx.doi.org/10.1016/j.tre.2014.05.015; accessed 10/12/2015.

Antle, J. 2015. "Climate change, vulnerability and food insecurity." *Choices* 30(2). http://www.choicesmagazine.org/choices-magazine/theme-articles/climate-change-and-agriculture-revisiting-the-evidence-and-potential-solutions/climate-change-vulnerability-and-food-insecurity; accessed 10/12/2015.

Attavanich, W; McCarl, BA; Ahmedov, Z; Fuller, SW; Vedenov, CV. 2013. "Effects of Climate Change on U.S. Grain Transport." *Nature Climate Change:* 3, 638–643. http://www.nature.com/nclimate/journal/v3/n7/full/nclimate1892.html; accessed 10/12/2015.

Blanc, E; Reilly, J. 2015. "Climate change impacts on U.S. crops." *Choices* 30(2). http://www.choicesmagazine.org/choices-magazine/theme-articles/climate-change-and-agriculture-revisiting-the-evidence-and-potential-solutions/climate-change-impacts-on-us-crops; accessed 10/12/2015.

Blanton, B. 2015. "USDA's perspective on Agricultural Transportation Priorities." Presentation for the Agricultural Transportation Summit, August 4, 2015, Rosemont, IL. http://www.ngfa.org/wp-content/uploads/USDA-AMSA-Bruce-Blanton.pdf; accessed 10/12/2015.

Bjerga, A. 2012. "Drought stalks the global food supply." *Bloomberg Business Week*, July 12, 2012. http://www.bloomberg.com/bw/articles/2012-07-05/drought-stalks-the-global-food-supply; accessed 10/12/2015.

Bosona, T; Gebresenbet, G. 2011. "Cluster building and logistics network integration of local food supply chain." *Biosyst. Eng.* 108(4): 293-302. http://www.sciencedirect.com/science/article/pii/S1537511011000134; accessed 10/12/2015.

Challinor, AJ; Watson, J; Lobell, DB; Howden, SM; Smith, DR; Chhetri, N. 2014. "A meta-analysis of crop yield under climate change and adaptation." *Nature Climate Change* 4: 287-291. http://www.nature.com/nclimate/journal/v4/n4/pdf/nclimate2153.pdf; accessed 10/21/2015.

Denicoff, MR; Prater, ME; Bahizi, P. 2014. "Corn Transportation Profile." U.S. Department of Agriculture, Agricultural Marketing Service. http://www.ams.usda.gov/sites/default/files/media/Corn%20Transportation%20Profile.pdf; accessed 10/21/2015.

Fischer, G; Shah, M; Tubiello, FN; van Velhuizen, H. 2005. "Socio-Economic and Climate Change Impacts on Agriculture: An Integrated Assessment, 1990–2080." *Philos Trans R Soc Lond B Biol Sci*, 360(1463): 2067-2083. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1569572/; accessed 10/12/2015.

Helmers, MJ; Zhou, X; Asbjornsen, H; Kolka, R; Tomer, MD; Cruse, RM. 2012. "Sediment removal by prairie filter strips in row-cropped ephemeral watersheds." *Journal of Environmental Quality* 41:1531-1539. https://dl.sciencesocieties.org/publications/jeq/abstracts/41/5/1531; accessed 10/29/2015.

Isakson SR. 2015. "Derivatives for Development? Small-Farmer Vulnerabilty and the Financialization of Climate Risk Management." *Journal of Agrarian Change*, 13(4): 569-580. http://onlinelibrary.wiley.com/doi/10.1111/joac.12124/abstract; accessed 10/21/2015.

Jokinen, P; Mononen, T; Sairinen, R. 2015. "Climate change and food security; three case studies on uncertainty." in *Climate Change Adaptation and Food Supply Chain Management*. Paloviita and Jarvela, editors. Routledge: London and New York.

Kammerer, JC. 1990. "Largest Rivers in the United States." U.S. Geological Survey Fact Sheet OFR 87-242. http://pubs.usgs.gov/of/1987/ofr87-242/; accessed 10/29/2015.

Key, N; Sneeringer, S; Marquardt, D. 2014. *Climate Change, Heat Stress and U.S. Dairy Production.* ERR-175. U.S. Department of Agriculture, Economic Research Service. http://www.ers.usda.gov/media/1679930/err175.pdf; accessed 10/12/2015.

Lengnick, L. 2015. *Resilient Agriculture: Cultivating Food Systems for a Changing Climate.* 1st ed. Gabriola Island, BC, Canada: New Society Publishers.

Lewandrowski, J; Zook, K. 2015. "GHG Mitigation in the Absence of a National Carbon Market." *Choices*, 30(2). http://www.choicesmagazine.org/magazine/pdf/cmsarticle_434.pdf; accessed 10/12/2015.

Lin, X; Dang, Q; Konar, M. 2014. "A Network Analysis of Food Flows within the United States of America." *Environmental Science & Technology* 48(10): 5439–47. http://pubs.acs.org/doi/abs/10.1021/es500471d; accessed 10/12/2015.

McCarl, BA. 2015a. "Elaborations on Climate Adaptation in U.S. Agriculture." *Choices* (30)2. http://www.choicesmagazine.org/choices-magazine/theme-articles/climate-change-and-agriculture-revisiting-the-evidence-and-potential-solutions/elaborations-on-climate-adaptation-in-us-agriculture; accessed 10/12/2015.

McCarl, BA. 2015b. "Climate Change, Choices, Agriculture and the Adaptation Imperative." Webinar: Council of Food, Agricultural and Resource Economics. https://www.youtube.com/watch?v=azDpCLyghfo; accessed 10/12/2015.

National Sustainable Agriculture Coalition. 2014a. "2014 Farm Bill Drill-down: Conservation-Crop Insurance Linkages" (blog post). http://sustainableagriculture.net/blog/2014-farmbill-hel-wetlands/; accessed 10/12/2015.

National Sustainable Agriculture Coalition. 2014b. "2014 Farm Bill Drill-down: Subsidy Reform and Fair Competition" (blog post). http://sustainableagriculture.net/blog/farm-bill-subsidy-reform/; accessed 10/12/2015.

Notaro, M; Lorenz, D; Hoving, C; Schummer, M. 2014. "Twenty-First-Century Projections of Snowfall and Winter Severity across Central-Eastern North America." *Journal of Climate*, 27: 6526–6550. http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-13-00520.1; accessed 10/12/2015.

Olmstead, J. 2011. "Feeding the World: Twelve years later, U.S. grain exports are up, so too is hunger." Institute for Agriculture and Trade Policy. http://www.iatp.org/documents/feeding-the-world; accessed 10/20/15.

Paloviita, A; Jarvela, M. eds. 2015. *Climate Change Adaptation and Food Supply Chain Management.* Routledge: London and New York.

Rose, S. 2015. "The inevitability of climate adaptation in U.S. agriculture." *Choices* 30(2). http://www.choicesmagazine.org/choices-magazine/theme-articles/climate-change-and-agriculture-revisiting-the-evidence-and-potential-solutions/the-inevitability-of-climate-adaptation-in-us-agriculture; accessed 10/12/2015.

Rotter, R; Hohn, J; Trnka, M; Fronzek, S; Carter, T; Kahiluoto, H. 2013. "Modeling shifts in agroclimate and crop cultivar response under climate change." *Ecology and Evolution* 3(12): 4197-4214. http://onlinelibrary.wiley.com/doi/10.1002/ece3.782/full; accessed 10/12/2015.

Sparger, A; Marathon, N. 2015. "Transportation of U.S. grains: A modal share analysis, 1978-2013 update." U.S. Dept. of Agriculture, Agricultural Marketing Service. http://www.ams.usda.gov/sites/default/files/media/ModalJune2015.pdf; accessed 10/12/2015.

Tolliver, D; Lu, P; Benson, D. 2013. "Comparing rail fuel efficiency with truck and waterway." *Transportation Research Part D: Transport and Environment* 24: 69-75. Elsevier. http://dx.doi.org/10.1016/j.trd.2013.06.002; accessed 10/20/2015.

U.S. Department of State. 2014. 2014 U.S. Climate Action Report to the UN Framework Convention on Climate Change. Sixth National Communication of the United States of America under the United Nations Framework Convention on Climate Change. http://www.state.gov/e/oes/rls/rpts/car6/index.htm; accessed 10/12/2015.

U.S Department of Transportation (DOT). 2015. "The Blue Paper." Beyond Traffic: 2045. https://www.transportation.gov/sites/dot.gov/files/docs/TheBluePaper.pdf; accessed 10/12/2015.

U.S. Environmental Protection Agency (EPA). 2013. "Fast Facts: U.S. Transportation Sector Greenhouse Gas Emissions 1990-2011." September 2013. http://www3.epa.gov/otaq/climate/documents/420f13033a.pdf; accessed 10/12/2015.

USDA Economic Research Service (ERS). 2015. "U.S Domestic Corn Use." http://www.ers.usda.gov/media/866543/cornusetable.html; accessed 10/29/2015.

USDA Natural Resources Conservation Service (NRCS). 2010. 2007 Natural Resources Inventory: Soil Erosion on Cropland. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/results/?cid=stelprdb1041887; accessed 10/12/2015.

USDA Natural Resources Conservation Service (NRCS). 2015. *Summary Report: 2012 National Resources Inventory.* Natural Resources Conservation Service, Washington, D.C., and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd396218.pdf; accessed 10/29/2015.

Wisconsin Initiative on Climate Change Impacts (WICCI). 2011. *Wisconsin's changing climate: Impacts and adaptation.* Nelson Institute for Environmental Studies, University of Wisconsin-Madison and the Wisconsin Department of Natural Resources, Madison, Wisconsin. http://www.wicci.wisc.edu/publications.php; accessed 10/12/2015.

World Economic Forum. 2015. *Global Risks 2015*. http://www.weforum.org/risks; accessed 10/12/2015.

Zhou, X; Helmers, MJ; Asbjornsen, H; Kolka, R; Tomer, MD; Cruse, RM. 2014. "Nutrient removal by prairie filter strips in agricultural landscapes." *Journal of Soil and Water Conservation* 69(1):54-64. http://www.jswconline.org/content/69/1/54.abstract?sid=357507b7-d94a-4604-bdda-5-a5fc41ef596; accessed 10/29/2015.

Zhuoting, W; Dijkstra, P; Koch, GW; Hungate, BA. 2012. "Biogeochemical and ecological feedbacks in grassland responses to warming." *Nature Climate Change* 2: 458-461. http://www.nature.com/nclimate/journal/v2/n6/full/nclimate1486.html; accessed 10/12/2015.

Authors: Michelle Miller, Center for Integrated Agricultural Systems, College of Agricultural and Life Sciences, UW-Madison and David Lorenz, Center for Climatic Research, Nelson Institute for Environmental Studies, UW-Madison.

Acknowledgements: This summary is made possible by the work of many people. Thanks to Olivia Dorothy, American Rivers; Mayor Tim Kabat, City of La Crosse, Wisconsin; Margaret Krome, Michael Fields Agricultural Institute; Mark Muller, The McKnight Foundation; Logan Peterman, Organic Valley; Pam Porter, UW-Madison CIAS; Tom Quinn, Wisconsin Farmers Union; and Sheri Walz, Wisconsin Department of Transportation.

Thank you to our reviewers: Diane Mayerfeld, George Reisted and Steve Ventura.
Editing: Cris Carusi and Ruth McNair. Layout: Ruth McNair. Project assistant: Rebecca Jolley.

UW-Madison Center for Integrated Agricultural Systems
1535 Observatory Drive • Madison, WI 53706
608-262-5200 • www.cias.wisc.edu

This report is part of a larger study at Vanderbilt University and the University of Wisconsin-Madison entitled "Estimating the future demands on agricultural freight transport in the Upper Midwest U.S. due to climate change using remote sensing and regional climate models." Funding for this project is from the National Center for Freight & Infrastructure Research & Education (CFIRE), University of Wisconsin-Madison. CFIRE is funded through the U.S. Department of Transportation's Research and Innovative Technology Administration.