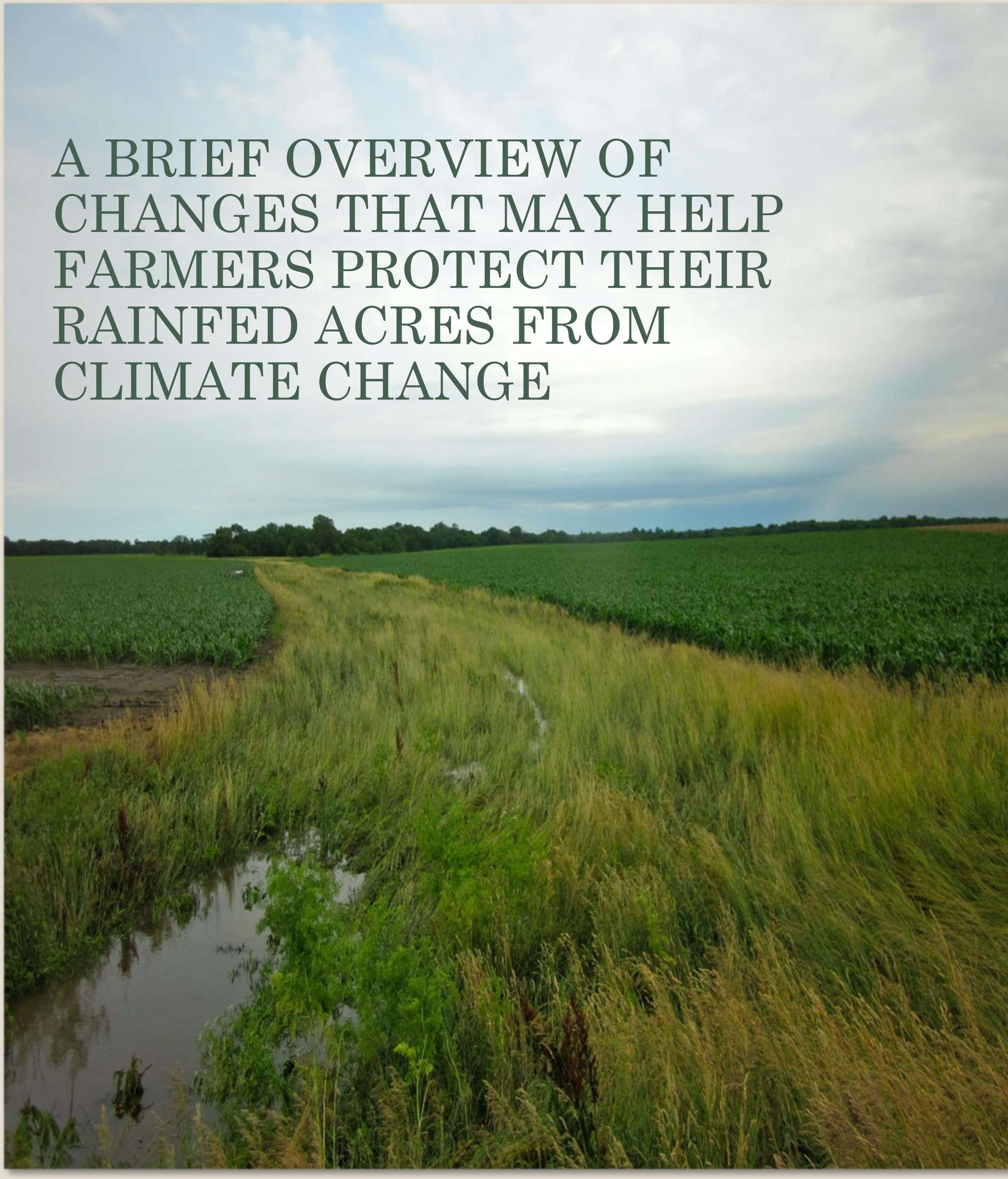
A BRIEF OVERVIEW OF CHANGES THAT MAY HELP FARMERS PROTECT THEIR RAINFED ACRES FROM CLIMATE CHANGE



American Farmland Trust

February 2023

A Brief Overview of Changes that may Help Farmers Protect Their Rainfed Acres Against Climate Change.[1]

Suggested Citation: American Farmland Trust (AFT). 2023. *A Brief Overview of Changes that may help farmers protect their rainfed acres against climate change. Washington, DC: American Farmland Trust.*

[1] **A companion brief for the FUT 2040 report on climate modeling:** Sorensen, A., R. Murphy, and T. Nogeire-McRae. 2023. *Farm Under Threat 2040: Projected Climate Impacts on the Growing Conditions for Rainfed Agriculture in the Contiguous United States.* Washington D.C.: American Farmland Trust

Table of Contents

Summary

The projected future climatic impacts on rainfed croplands spotlighted in the maps from American Farmland Trust's Farms Under Threat 2040 climate modeling report[1] show that farmers will need to make changes in their operations to keep much of the nation's rainfed cropland productive in the coming decades. Some level of climate change is now unavoidable due to the greenhouse gas (GHG) emissions already in the atmosphere. However, many solutions already exist that can help farmers adjust and build resilience to the current and future climate. Many of these options also help farmers rapidly reduce their GHG emissions and maximize soil carbon storage so they can help limit catastrophic warming while also making their farms more resilient. This brief provides an overview of the types of climate adaptations or adjustments that may help farmers protect their rainfed acres against climate change.

Introduction

Although land use decisions by farmers are influenced by factors other than climate (e.g., market demands, existing infrastructure, and resources), changes in the climate will govern where and what crops can be grown, management and inputs that will be needed, and how yields will change. [2] Changes in average temperatures and temperature extremes are particularly important. Temperature affects the rate at which plants develop and its effects can be exacerbated by water deficits or by excess soil water.[3] High temperatures speed annual grain crops through their growth stages, especially grain-filling stages, reducing the amount of grain they produce. Many crops are stressed at temperatures above 90 to 95 degrees Fahrenheit, depending on water availability. As days above 93 F increase in frequency, even areas where sufficient moisture is available become less suitable for rainfed agriculture.[4] Other climate-related stressors include a projected increase in extreme weather events, which can directly damage crops at specific developmental stages or make the timing of field applications more difficult.[5] Farmers across the United States are already dealing with climate-related stressors like more torrential downpours and hailstorms;[6] more prolonged droughts combined with heat waves;[7] and increases in the severity of crop damage by pests, pathogens, and viral diseases.[8]

To project the impacts of climate to 2040, American Farmland Trust (AFT) used climate and soil variables specific to each 30 by 30-meter pixel location across the U.S. to model the likelihood that farmers will still be able to grow their current crop varieties using their present-day production practices for rainfed cropland in general, and more specifically, for rainfed corn, winter wheat, and apples by 2040. Most of the cropland acres in the contiguous U.S. are rainfed (83% to 86%) and rely on timely and predictable rainfall for production.[9] The AFT models[10] focus on projected changes in average temperature and rainfall and their interactions with soils and terrain. The models do not include future damage from extreme weather events and biotic stressors like pests and plant diseases. This brief overview showcases options to help farmers adapt to the projected changes in the suitability of their rainfed cropland to support cultivation.

Protecting rainfed acres against climate change

In areas where AFT maps indicate declines in the likelihood of cultivation, farmers and land managers can start now to improve the health and fertility of their soils. In many places, this may include helping soils hold more moisture in dry times and changing crop varieties or types of crops as well as planting times and rotations. Two practices essential to improving soil health and a farm's resilience to climate change are planting cover crops and reducing or eliminating tillage (see below). Diversifying a crop rotation can also improve soil health as well as crop productivity, and lower fertilizer and pesticide needs – thus making the farm more ecologically and economically resilient to climate change.[11] Further, retiring marginal lands diversifies the landscape surrounding cropland and helps provide year-round support for beneficial insects and other animals that provide biological control of crop pests.[12] Infrastructure and equipment changes will likely also help ease transitions to more climate-smart agriculture. Examples include updating farm machinery to match new farm practices such as precision nitrogen management and to improve fuel efficiency, upgrading building facilities to handle expected increased snow or wind loads, and installing or improving irrigation systems.[13] If feasible, the use of supplemental irrigation may help increase available soil moisture in some areas and provide a critical buffer during periodic droughts.[14]

Since the AFT models did not account for climate extremes, even in areas where the likelihood of cultivation remains essentially unchanged or increases, farmers will still benefit from implementing climate adaptation strategies that anticipate the increasing likelihood and intensity of extreme downpours and droughts. Improving soil heath and the farm's resilience can help buffer against more severe weather events and variability.

In areas where opportunities to cultivate new land may emerge, great care must be taken. Converting grasslands, lands in the Conservation Reserve Program (CRP), and other lands into cropland drives significant losses of soil carbon, biodiversity, and other ecosystem services. Ninety percent of global deforestation is driven by agriculture.[15] Years of research on the ecological consequences of transitioning land out of the CRP show that tillage can eliminate any soil health improvements resulting from grassy covers in as little as one year, so the preferred strategy, when CRP conversion is necessary, is to use no-till.[16] Farmers can also use crop rotations that include hay to maintain soil health improvements when land is brought back into row crop production. Growers may partially offset the GHG emissions resulting from cropland expansion northward by planting revenue-generating trees like walnut and incorporating permanent vegetation into their operations. Updating machinery, growing new crops, adding cover crops, switching to no-till, and planting trees will require financial and technical assistance.

As the severity and frequency of rain events in many areas of the U.S. increases, more cropland soils will be vulnerable to erosion. Cover crops and no-till provide many benefits to farmers, including significantly reducing erosion risks.[17] Crops that produce large amounts of residue (e.g., corn, sorghum, or small grains) or form dense canopies (e.g., drilled soybeans, which reach canopy more quickly than conventionally sowed beans, small grains, alfalfa, or hay) are also beneficial.

Building soil health as the first line defense

As a first line defense, building soil organic carbon is critical in nearly any cropping system. It both increases climate resiliency and draws down carbon dioxide from the atmosphere – a key to reducing future climate severity. Improving soil health is also among the least costly and most immediate actions that can help reduce GHG emissions on a meaningful scale. This can serve as an important bridge until new climate-friendly energy and transportation technologies are developed.

By improving soil health, farmers are improving soil structure and soil organic carbon content, which can enable soils to absorb and drain more water more quickly during heavy rains. This recharges the soil profile and groundwater, reduces erosion and downstream flood risk, and helps the soil hold more water during droughts and absorb more carbon. In reduced or no-till corn fields, soil temperatures in the surface soil layers can be 8-10 degrees F lower than disk-tilled fields, which early in the season can delay germination, but later in the growing season enhances root growth, and nutrient and water uptake during heat waves.[18]

Soil health improvements translate into economic benefits as well. In 13 soil health case studies from across the U.S., AFT found that study participants received, on average, nearly $3 back for every dollar they invested in improving their soils.[19] Steps that farmers can take to improve soil health follow the four principles of soil health: **minimize disturbances** by reducing tillage depth, intensity, and frequency and reducing pesticide inputs; **maximize soil cover** through cover crops, mulching, reduced tillage, and leaving crop residues; **maximize the continuous presence of living plant roots** by using cover crops, longer rotations, planting forage and biomass, and incorporating perennial crops into rotations; and **maximize biodiversity** (e.g., diversifying crop rotations and integrating livestock into cropping systems).[20] These practices rely on current technology and knowledge and are a key strategy in building more resilient landscapes. However, they take time. It can take anywhere from 3 to 5 years to start seeing the benefits and 10 to 50 years to fully restore soil health depending on the system, region, soil type, and climatic conditions.[21]

Using soil amendments like compost, manure, or biochar can also help. Of note, biochar shows promise as a way to sequester carbon in soil; retain water, carbon, and nitrogen in the soil; reduce GHG emissions; and potentially increase agricultural productivity.[22] Biochars are created from the pyrolysis of a variety of feedstock including corn stalks, wood, and even manure and resulting products have variable properties and uses. Sustainably produced, fit-for-purpose biochar has the potential to be a valuable tool as a soil amendment for farmers and landowners. AFT, with the Foundation for Food and Agriculture Research and the National Center for

Appropriate Technology, organized a Convening on Biochar Research and Commercialization event and published a summary of the event and findings, both available on the Farmland Information Center website.

Farmers can further improve rainfall absorption and reduce erosion by establishing trees or shrubs along field borders, alley cropping with trees within crop fields, riparian forest buffers, hedgerow plantings, strips of perennial grasses, and legume covers.[23] Along with sequestering carbon, trees can provide a supplemental source of income (berry bushes and fruit and nut trees), support beneficial insects and other wildlife and native plants. In Iowa, planting strips of native prairie plants within existing crop fields builds soil carbon while substantially reducing erosion and nutrient loss and supporting pollinators and grassland birds.[24] In most instances, successful implementation of agroforestry and prairie strips will require technical and financial assistance to optimize productivity and GHG emission reductions.

Adopting supplemental irrigation and doing whole-farm water planning may allow growers to mitigate climate effects in some regions. Irrigation can supplement available soil moisture and provide a critical buffer during periodic droughts. However, demand for water is and will be increasing in many sectors to support development and adapt to climate change, putting increasing pressure on limited surface and groundwater resources. In areas where irrigation is not feasible, farmers can make other changes like improving soil health and growing more resilient crop varieties and types.

Specific considerations for corn, winter wheat, apples, and coastal flooding

For rainfed corn: To adapt corn systems to climate change, corn growers can use precision nitrogen management, diversify crop rotations by adding a small grain or hay, plant cover crops to build soil carbon and take up excess nitrogen, and use no-till to conserve soil, water, and carbon.[25] These practices may also help minimize the environmental impacts of growing corn, which are likely to intensify as more intense rainstorms occur, inducing soil microbes to convert soil nitrogen (N) to a potent GHG (nitrous oxide, N_2O) and washing a greater proportion of excess nitrogen and phosphorus fertilizer from fields into streams, rivers, lakes, and the ocean.

Numerous advances in crop cultivars to enhance the tolerance of corn to extreme climate conditions are also helping farmers adjust. However, in years when more normal climatic conditions prevail, these new crop cultivars are at a disadvantage.[26] Between 1951 and 2017, the use of heat- and drought-tolerant corn varieties in hot and dry years increased yields by 33% but yields dropped by 41% in years that were not too hot or dry.[27] In addition, corn yields have become more sensitive to soil water storage capacity as well as actual soil moisture, perhaps reflecting the continued increases in hybrid sowing density and yield potential, which increase crop water needs.[28] Breeders will need to develop varieties that are not only adapted to withstand extreme heat and drought conditions but that are also productive under a wider range of climate conditions.[29]

For rainfed winter wheat: Wheat has a very low total water requirement overall and is characterized by its ability to withstand substantial reductions in water availability over relatively long periods of time.[30] Wheat growers can reduce the impact of water shortages by: 1) shifting the wheat growing season by sowing earlier or later (if fields are not too wet) or by using early-ripening cultivars; 2) adding full or partial irrigation; 3) increasing water use efficiency through soil health practices that enhance rainfall infiltration and reduce soil evaporation (e.g., minimizing tillage and covering the soil surface with plant residue); and 4) using wheat varieties with enhanced drought and heat tolerance.[31] Enhancing rainfall infiltration will also allow growers to get out in the fields and plant sooner following rain events.

For apples: Apple growers have an assortment of adaptive technologies they can try. [32] These include:

- Using drip irrigation during dry spells.
- Using shade cloth netting to reduce heat stress, sunburn damage.
- Eliminating overhead irrigation to conserve water.
- Using tall fans or stack heaters to protect apples from late frost damage.
- Planting cover crops to keep orchards cooler, reduce the need for fertilizers, and reduce erosion.
- Spraying with calcium carbonate or wax emulsion sprays to protect apples from sunburn; scheduling irrigation to reduce heat stress.
- Adding more drainage lines to handle excessive rainfall.

Most of these methods will add significant production costs and shifts to new production areas will incur substantial infrastructure costs.

Developing new cultivars that are more productive under lower chill conditions may be the most viable way to adapt but will require investments in research to understand the biological basis for chilling and a greater emphasis on breeding programs.[33] And while longer-term, proactive adjustments like diversifying crops, planting new varieties, and improving soil health will be necessary to make orchards more resilient, growers' uncertainty about future climate change may make some hesitant to make these changes.[34] This hesitancy suggests that growers could benefit from talking about climate change with trusted advisors, learning about the economic costs and benefits of adaptation options. Increasing the federal investments in variety development for changing conditions will also help ease this transition.

For coastal flooding: To stay in farming in more frequently flooded coastal areas, in the short term farmers can remove excess salt from the soils through irrigation, adding gypsum to decrease excess salt in the soils and using cover crops to break up the soil and help salt leach down through it.[35] Researchers are currently testing out varieties of barley, sorghum, salt tolerant soybeans, switchgrass, and other plants to see how well they can withstand salty soils and periodic flooding.[36] Farmers can also use conservation practices on or next to salt-impacted fields. For example, they can plant native warm season grasses like coastal panicgrass or eastern gamagrass to act as a vegetative barrier and provide ecosystem services such as carbon capture, wildlife habitat and water quality improvements. When the soil finally becomes too wet and salty, the land can be turned into marsh habitat and placed in a conservation easement program.[37]

Increasing the resiliency of rainfed acres going forward

The strategies and practices adopted by farmers to address climate resilience and meet both adaptation and mitigation goals are shaped by their production context as framed above. Proactive adaptation strategies are often time and cost intensive, and farmers can run into structural barriers to implementing adaptation measures in order to participate in programs like crop insurance. Holistic (financial, economic, and social) support of farmers' adaptive capacity is crucial to the future of farm viability and food production in our country.

The 2023 Farm Bill offers the opportunity to help farmers and ranchers adapt to and mitigate climate change while also improving water and air quality, soil health, and even profitability. To learn more about what we can accomplish together, AFT has laid out an action plan to build on-farm resilience so our best land remains in production.

Endnotes

[1] Sorensen, A., R. Murphy, and T. Nogeire-McRae. 2023. *Farms Under Threat 2040: Projected Climate Impacts on the Growing Conditions for Rainfed Agriculture in the Contiguous United States*. Washington D.C.: American Farmland Trust.

[2] Lobell, D. and Burke, M. 2008. *Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation*. Environmental Research Letter Volume 3(2008) 034007. June 24, 2008. 8 pp.; Vogel, E., M. Donat, L. Alexander, M. Meinshausen, D. Ray, D. Karoly, N. Meinshausen, and K. Frieler. 2019. *The effects of climate extremes on global agricultural yields*. Environmental Research Letters Volume 14(5); and Burchfield, E. 2022. *Shifting cultivation geographies in the Central and Eastern US*. Environmental Research Letters Volume 17(5).

[3] Hatfield, J. and J. Prueger. 2015. *Temperature extremes: Effect on plant growth and development*. Weather and Climate Extremes Volume 10, Part A: 4-10. December 2015.

[4] Bradford, J., D. Schlaepfer, W. Lauenroth and C. Yackulic. 2017. *Future soil moisture and temperature extremes imply expanding suitability for rainfed agriculture in temperate drylands*. Scientific Reports Volume 7(1). October 2017.

[5] Tubiello, F., J. Soussana, and S. Howden. 2007. *Crop and pasture response to climate change*. PNAS Volume 104(50). December 11, 2007.

[6] Trapp, R., N. Diffenbaugh, H. Brooks, M. Baldwin, E. Robinson, et al. 2007. *Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing.* PNAS Volume 104(50): 19719-19723. December 11, 2007; and Brooks. H. 2013. *Severe thunderstorms and climate change.* Atmospheric Research Volume 123:129-138. April 2013.

[7] Singh, J., M. Ashfaq, C. Skinner, W. Anderson, V. Mishra, and D. Singh. 2022. *Enhanced risk of concurrent regional droughts with increased ENSO variability and warming.* Nature Climate Change 12, 263-170 (2022).

[8] Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, et al. 2012. *Climate Change and Agriculture in the United States: Effects and Adaptation*. USDA Technical Bulletin 1935. Washington, DC. 186 pages; Savary, S., L. Willocquet, S. Pethybridge, P. Eskler, N. McRoberts, and A. Nelson. 2019. *The global burden of pathogens and pests on major food crops.* Nature Ecology & Evolution, Volume 3, March 2019:430-439; Skendzic, S., M. Zovko, I. Zivkovic, V. Lesic, and D. Lemic. 2021. *The impact of climate change on agricultural insect pests.* Insects 2021, Volume 12, 440. May 12, 2021; and Chaloner, T., S. Gurr, and D. Bebber. 2021. *Plant pathogen infection risk tracks global crop yields under climate change.* Nature Climate Change Volume 11, August 2021:710-715.

[9] Xie, Y., T. Lark, J. Brown, and H. Gibbs. 2019. *Mapping irrigated cropland extent across the conterminous United States at 20 m resolution using a semi-automatic training approach on Google Earth Engine.* ISPRS Journal of Photogrammetry and Remote Sensing Volume 155:136-149. September 2019.

[10] Spawn-Lee, S. and T. Lark. 2022. *Description of the approach, data and analytical methods used for the Farms Under Threat projections of climate-related crop and land-use suitability, and sea-level*

rise. Nelson Institute Center for Sustainability and the Global Environment (SAGE). University of Wisconsin-Madison. June 2022.
[11] Mortensen, D. and R. Smith. 2020. *Confronting barriers to cropping system diversification. Frontiers in Sustainable Food Systems.* Agroecology and Ecosystem Services. November 10, 2020; and Tamburini, G., R. Bommarco, T. Wanger, C. Kremen, M. van der Heijden, M. Liebman, and S. Hallin. 2020. *Agricultural diversification promotes multiple ecosystem services without compromising yields.* ScienceAdvances Volume 6(45), November 4, 2020.
[12] Landis, D. and S. Gage. 2015. *Arthropod diversity and pest suppression in agricultural landscapes*, pp. 188-212. In S.K Hamilton, J.E. Doll, and G. P. Robertson, eds. The Ecology of Agricultural Landscapes: Long-term research on the path to sustainability. Oxford University Press, New York, New York, USA.
[13] Janowiak, M., D. Dostie, M. Wilson, M. Jucera, R. H. Skinner, J. Hatfield, D. Hollinger, and C. Swanston. 2016. *Adaptation resources for agriculture: Responding to climate variability and change in the Midwest and Northeast*. USDA Technical Bulletin 1944, October 2016. 72 pp.
[14] Hrozenick, R. and M. Aillery. *Trends in U.S. irrigated agriculture: Increasing resilience under water supply scarcity.* USDA Economic Research Service. Economic Information Bulletin Number 229. December 2021. 55 pp.
[15] Food and Agriculture Organization of the United Nations (FAO). 2022. *The state of the world's land and water resources for food and agriculture – systems at a breaking point.* Main report. Rome.
[16] U.S. Department of Agriculture Natural Resources Conservation Service. 2012. *Converting sod to grain crops: the RIGHT way*. USDA NRCS fact sheet. August 2012. 3 pp.
[17] Claassen, R., M. Bowman, J. McFadden, D. Smith, and S. Wallander. 2018. *Tillage intensity and conservation cropping in the United States.* USDA Economic Research Service. Economic Information Bulletin No. 197. September 2018. 27 pp.
[18] Irmak, S. 2016. *Impacts of extreme heat stress and increased soil temperature on plant growth and development*. Institute of Agriculture and Natural Resources Cropwatch. University of Nebraska-Lincoln. Accessed online July 2022.
[19] Bodell, J., B. Brandt, E. Bruner, P. Lum, M. Perez, A. Ristow, F. Schwartz, B. Wiercinski, and E. Yeatman. 2019. *Soil Health Case Studies*. American Farmland Trust, Northampton, MA.; and USDA Natural Resources Conservation Service. July 30, 2019, and *American Farmland Trust Soil Health Case Study Findings*, September 2022.
[20] Teague, W., S. Apfelbaum, R. Lal, U.P. Kreuter, J. Rowntree, C. Davies, R. Conser, M. Rasmussen, J. Hatfield, T. Wang, F. Wang, and P. Byck. 2016. *The role of ruminants in reducing agriculture's carbon footprint in North America*. Journal of Soil and Water Conservation March 2016, 71 (2) 156-164; and Roesch-McNally, G., J. Moore-Kucera, and C. Owens. 2019. *Applying soil health management systems to reduce climate and weather risks in the Northwest*. USDA-NRCS Factsheet.
[21] Janowiak, M., D. Dostie, M. Wilson, M. Jucera, R. H. Skinner, J. Hatfield, D. Hollinger, and C. Swanston. 2016. *Adaptation resources for agriculture: responding to climate variability and change in the Midwest and Northeast*. USDA Technical Bulletin 1944, October 2016. 72 pp.; and Bruner, E., J. Moore, M. Hunter, G. Roesch-McNally, T. Stein, and B. Sauerhaft. 2020. *Combatting climate change on U.S. cropland. Affirming the technical capacity of cover cropping and no-till to sequester carbon and reduce greenhouse gas emissions*. American Farmland Trust. 32 pp.
[22] Krishnakumar, S., A. Rajalakshmi, B. Balaganesh, P. Manikandan, V. Chelladurai, and V. Rajendran. 2014. *Impact of Biochar on Soil Health*. International Journal of Advanced Research. 2. pp 933-950.
[23] Moore-Kucera, J. 2019. *Testimony of Dr. Jennifer Moore-Kucera,* Climate Initiative Director of American Farmland Trust, October 30, 2019.
[24] Pérez-Suárez, M., M. Castellano, R. Kolka, H. Asbjornsen, and M. Helmers. 2014. *Nitrogen and carbon dynamics in prairie vegetation strips across topographical gradients in mixed Central Iowa agroecosystems*. Agriculture, ecosystems & environment, Volume 188, 1-11; Janowiak, M., D. Dostie, M.

Wilson, M. Jucera, R. H. Skinner, J. Hatfield, D. Hollinger, and C. Swanston. 2016. *Adaptation resources for agriculture: responding to climate variability and change in the Midwest and Northeast*. USDA Technical Bulletin 1944, October 2016. 72 pp.; and Schulte, L., J. Niemi, M. Helmers, M. Liebman, J. Arbuckle, D. James, et al. 2017. *Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands*. Proceedings of the National Academy of Sciences, Volume 114(42), 11247-11252.

[25] Wright Morton, L., L. Abendroth, R. Anex, J. Arbuckle, R. Arritt, M. Castellano, et al. 2016. *Climate and Managing Corn-Soybean Agroecosystems I: Findings, Implications and Recommendations*. Technical Report Series: Findings and Recommendations of the USDA-NIFA funded Climate and Corn-based Cropping Systems Coordinated Agricultural Project. Iowa State University, Ames, IA. Vol 1 of 5. Pub. No. CSCAP-0195-2016; and Liu, L. and B. Basso. 2020. *Impacts of climate variability and adaptation strategies on crop yields and soil organic carbon in the U.S. Midwest.* PLoS ONE Volume 15(1):e0225433.

[26] Yu, C., R. Miao, and M. Khanna. 2021. *Maladaptation of U.S. corn and soybeans to a changing climate.* Scientific Reports Volume 11, Article No. 12351 (2021). Published June 11, 2021.

[27] Yu, C., R. Miao, and M. Khanna. 2021. *Maladaptation of U.S. corn and soybeans to a changing climate.* Scientific Reports Volume 11, Article No. 12351 (2021). Published June 11, 2021.

[28] Lobell, D. J. Deines, and S. Tommaso. 2020. *Changes in the drought sensitivity of US maize yields*. Nature Food Volume 1, November 2020: 729-735

[29] Yu, C., R. Miao, and M. Khanna. 2021. *Maladaptation of U.S. corn and soybeans to a changing climate.* Scientific Reports Volume 11, Article No. 12351 (2021). Published June 11, 2021.

[30] Trnka, M., S. Feng, M. A. Semenov, J. E. Olesen, K. C. Kersebaum, et al. 2019. *Mitigation efforts will not fully alleviate the increase in water scarcity occurrence probability in wheat-producing areas.* Science Advances, Volume 5(9). September 25, 2019.

[31] Hatfield, J. and C. Dold. 2018. *Agroclimatology and wheat production: coping with climate change*. Frontiers in Plant Science Volume 9, 2018; and Trnka, M., S. Feng, M. A. Semenov, J. E. Olesen, K. C. Kersebaum, et al. 2019. *Mitigation efforts will not fully alleviate the increase in water scarcity occurrence probability in wheat-producing areas*. Science Advances, Volume 5(9). September 25, 2019.

[32] Houston, L., S. Capalbo, C. Seavert, M. Dalton, D. Bryla, and R. Sagili. 2018. *Specialty fruit production in the Pacific Northwest: adaptations strategies for a changing climate*. Climatic Change 146, 159-171 (2018).

[33] Houston, L., S. Capalbo, C. Seavert, M. Dalton, D. Bryla, and R. Sagili. 2018. *Specialty fruit production in the Pacific Northwest: adaptation strategies for a changing climate.* Climatic Change 146, 159-171 (2018).

[34] Linder, J. and V. Campbell-Arvai. 2021. *Uncertainty in the "new normal": understanding the role of climate change beliefs and risk perceptions in Michigan tree fruit growers' adaptation behaviors*. Weather, Climate and Society Volume 13 (3). March 2021.

[35] Tully, K., K. Gedan, R. Epanchin-Niell, A. Strong, E. Bernhardt, T. BenDor, M. Mitchell, J. Kominoski, T. Jordan, S. Neubauer, et al. 2019. *The invisible flood: the chemistry, ecology, and social implications of coastal saltwater intrusion.* BioScience Volume 69, Issue 5, May 2019.

[36] USDA Northeast Climate Hub. *Farming on a Saltier Coast*. USDA Northeast Climate Hub. C, Miller. USDA-NRCS Cape May Plant Materials Center.

[37] Tully, K., K. Gedan, R. Epanchin-Niell, A. Strong, E. Bernhardt, T. BenDor, M. Mitchell, J. Kominoski, T. Jordan, S. Neubauer, et al. 2019. *The invisible flood: The chemistry, ecology, and social implications of coastal saltwater instruction.* BioScience Volume 69, Issue 5, May 2019.