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# Climate Change Impacts on Minnesota Agriculture


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## Methods and Supplementary Materials

Please visit www.climatehubs.usda.gov/hubs/midwest/assessing-impacts-climate-change-midwest-agriculture for the methods and supplementary materials associated with this report.

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# Climate Change Impacts On Minnesota Agriculture

Agriculture and forestry are critically important aspects of economic and social life across Minnesota. The state has 26 million acres of farmland and 68,000 farms.[1,2] In 2023, the market value of agricultural products sold totaled more than $21 billion.[1,2,3,4] Agricultural production in the state is diverse, with key crops including corn for grain, soybeans, hay, wheat, potatoes, sweet corn, sunflowers, peas, oats, canola, barley, beans, rye, and sugar beets.[3,5] Minnesota ranked 1st in the nation for production of sugar beets, oats, wild rice, and red kidney beans in 2023. Livestock production is focused on hogs, dairy, beef, and turkeys. In 2023, Minnesota was ranked 2nd in the nation for hogs, and 7th for dairy, and is currently 1st in turkey production.[2,6] Minnesota also has a substantial forest resources economy, with estimated economic impacts from forest products industries totaled over $9 billion in 2017.[3,4] In 2019, the state had approximately 15.8 million acres of productive forestland.[7]

Like other regions in the United States, agricultural and forestry productivity in Minnesota is vulnerable to weather and climate variability. In recent decades, changes in Minnesota's climate, including temperature and precipitation variability, have emerged, with continued change expected in the future. Although some of these shifts may appear minor now, agriculture is already being impacted by observed climate changes. Importantly, the impacts of climate change on the agricultural and forestry sectors extend beyond physical impacts to farms and forestlands but also bring direct and indirect impacts to the overall cultural, social, and economic resilience of Minnesota's communities. In 2018, agricultural exports were the state's primary industry and Minnesota was the 4th largest agricultural exporting state in the country.[1] Therefore, when considering impacts on the agricultural and forestry sectors in Minnesota, climate change-driven stressors and disruptions can emerge well outside the geography of the state.

## Observed Changes to Minnesota's Climate

Observational changes in Minnesota's climate are calculated from gridded meteorological data from 1979 to 2021 (period of record for the dataset) by partners at Michigan State University and GLISA.[8] A summary of the historical, observed changes in Minnesota's climate are described as follows.

Temperature

- Average annual temperature increased by 1.2°F between 1979 and 2021. Between 1895 and 2021, the average annual temperature increased by 3.0°F (see Table 1, page 2).[9]
- Average fall (September- November) temperature has increased by 2.9°F between 1979 and 2021 (see Table 1, page 2). This warming may be driving an increase in the length of the growing season in parts of Minnesota (see Figure 5, page 8).
- Winters have shown pronounced warming in recent decades compared to other seasons. Between 1979 and 2021, the average daily winter low temperatures rose more than 15 times faster than average daily summer high temperatures. The frequency of -35°F readings in northern Minnesota and -25°F readings in the south have fallen by up to 90%.[9]

Precipitation

- Average annual precipitation has risen by 2.8" between 1979 and 2021, with the greatest increases observed during the winter and spring (see Table 1, page 2).
- 30-year average annual precipitation increased the most in SE and SC Minnesota (1-2" or more) between the 1981-2010 and 1991-2020 periods (see Figure 1, page 2).
- Extreme precipitation events (greater than 2") have become more frequent (see Table 1). Since 2000, there has also been an increase in the episodes of extreme rain that cover large areas.[9]
- Each of the top-10 combined warmest and wettest years on record have all occurred between 1998 and 2020.[9]

*Table 1. Observed changes in Minnesota's climate based on data from 1979-2021. "Average" refers to the 1979-2021 average, and "Change" refers to change in the value between 1979 and 2021 based on a trend analysis.*

| | Annual (Jan – Dec) | | Summer (Jun – Aug) | | Fall (Sep – Nov) | | Winter (Dec – Feb) | | Spring (Mar – May) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Average** | **Change** | **Average** | **Change** | **Average** | **Change** | **Average** | **Change** | **Average** | **Change** |
| **Temperature** | 41.8 °F | +1.2 °F | 67.3 °F | +1.2 °F | 44.0 °F | +2.9 °F | 13.5 °F | +0.6 °F | 42.3 °F | -0.9 °F |
| **Precipitation** | 28.0" | +2.8" | 11.8" | 0" | 6.9" | +0.6" | 2.4" | +1.0" | 6.9" | +1.2" |
| **Vapor Pressure Deficit** | 5.0 mb | +0.1 mb | 9.1 mb | +0.6 mb | 4.3 mb | 0 mb | 1.1 mb | 0 mb | 5.4 mb | -0.9 mb |
| **Extreme precipitation[†] (days with 2")** | 0.4 days | +0.8 days | | | | | | | | |
| **Growing Season Length (frost-free days)** | 146.3 days | -0.4 days | | | | | | | | |

[†] The average value being less than 1 means that, on average, these events don't happen every year. On average, Minnesota observed one of these events every 2.5 years between 1979 and 2021. The change value represents the slope of the linear regression performed on the extreme precipitation frequency data, showing an increase in the frequency of events.

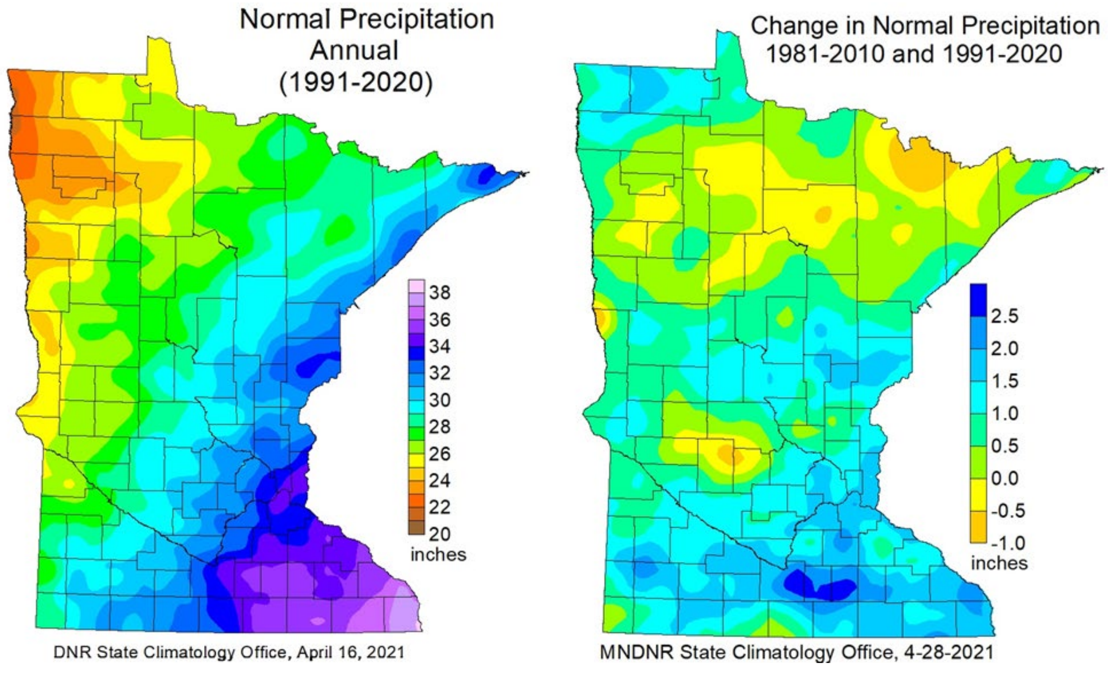



*Figure 1. Minnesota 30-year average annual precipitation for 1991-2020 (left) & the change in the 30-year average precipitation between 1981-2010 and 1991-2020. Image source: Minnesota State Climatology Office.*

## Observed Impacts on Agriculture and Forestry

- Longer growing seasons and increased temperature provide opportunities to plant alternative varieties of crops and trees.
- Greater frequency of heat stress on trees, crops, livestock, and farmworkers.
- Increased risk of both drought and seasonal flooding.
- Increased weed, pest, and disease pressure as well as animal pathogens.

- More erratic spring freeze/thaw cycles that may damage trees and fruit crops.
- Higher production costs and lower yields for some crops.[10,11]
- Greater swings in soil moisture content, resulting in delayed agricultural planting, higher erosion, decomposition of organic matter, and nutrient loss, as well as hampering the ability of loggers to access forest stands.[12]
- Changes to the composition and extent of forest cover, especially for species near the southern edge of their native range, such as quaking aspen, paper birch, balsam fir, white spruce, jack pine, and red pine.[12]
- Increases in the number and severity of forest disturbances due to extreme storms, wildfire, and invasive species and disease.

## Future Climate Change

Models of future climate indicate that temperatures are projected to continue to warm, precipitation is expected to become more variable and extreme, and the growing season is anticipated to continue to lengthen. The climate projections in this section are based on the average of 17 different regional climate models.[8] Two possible futures are presented: a moderate emissions scenario in which greenhouse gas emissions peak around mid-century (RCP 4.5) and then slowly decline, and a higher emissions scenario in which emissions continue to rise throughout the 21st century (RCP8.5).[13] Careful planning and adaptive actions can lower the risks of climate change impacts for producers and the agricultural and forestry sectors more broadly. There are many ways to adapt to climate change based on emerging impacts and the needs of a particular farm, crop, or community, and some examples are presented below.

### Projected Temperature Change

All available climate model projections indicate that Minnesota can expect to see continued warming in the future, with fewer extremely cold nights, more very warm nights, and more very hot days.

Depending on the emissions scenario, climate models project that annual average temperatures in Minnesota will increase over historical baselines by 3.5°F to 6.0°F by mid-century (2040-2059), and by 5.8°F to 10°F by late-century (2080-2099).[14,15]

The models summarized by Michigan State University indicate that in all scenarios, Minnesota will see freezing conditions reduced dramatically, with an increase in very warm nights, hot days, and very hot days (Table 2). Although these changes are most pronounced at the end of the century and in the high-emissions scenarios, even the moderate, mid-century projections indicate major changes in Minnesota's cold and hot-weather climatologies that could have important ramifications for agriculture and forestry.

*Table 2. Mean temperature threshold changes and model ranges for Minnesota compared to the 1979 – 2005 period.*

| | **Low temp. ≤ 32°F** | **Low temp. ≥ 80°F** | **High temp. ≥ 86°F** | **High temp. ≥ 95°F** |
|---|---|---|---|---|
| **Mid-century, moderate emissions** | -27.2 days *(-46.6 to -12.5)* | +0.1 days *(0.0 to +0.3)* | +60.7 days *(+41.0 to +73.5)* | +5.5 days *(+0.8 to +8.9)* |
| **Mid-century, higher emissions** | -32.8 days *(-58.1 to -31.7)* | +0.4 days *(0.0 to +0.93)* | +68.4 days *(+49.7 to +82.4)* | +8.5 days *(+2.2 to +14.2)* |
| **Late century, moderate emissions** | -37.5 days *(-60.4 to -20.7)* | +0.7 days *(0.0 to +2.6)* | +70.6 days *(+47.6 to +88.5)* | +10.22 days *(+1.57 to +21.4)* |
| **Late century, higher emissions** | -63.1 days *(-92.0 to -36.8)* | +5.84 days *(+0.2 to +17.3)* | +97.7 days *(+71.3 to +119.4)* | +31.8 days *(+7.5 to +60.2)* |

## What Does This Mean for Agriculture and Forestry?

### Heat Stress

- Increased heat stress severely impacts farmers and loggers, and animals. Among livestock, high heat can decrease meat and milk quality and quantity, and egg production. High heat during the growing season may also stress cool season crops like broccoli and cabbage.[10,16,17,18]
- Farmworkers who work predominantly outdoors are also particularly vulnerable to heat-related illness.[20]
- The frequency of short-term and rapid onset drought during the summer is potentially higher due to higher temperatures and increased precipitation variability.[21]

### Soil Impacts

- Decreased soil moisture during the growing season affects agricultural plant physiology, potentially leading to an increased risk of reduced yields or crop losses, but uncertainty remains.[10,19] Crop genetics and field management will be key to mitigating these potential yield losses. Decreased soil moisture can also increase chances for forest wildfire, as well as forest pest or pathogen outbreaks due to water stress.[12]
- Future precipitation is expected to be more extreme with larger amounts during shorter periods of time. This will lead to more runoff and evaporation, with less water staying in the soil.[22]
- Increased soil temperatures affect the appropriate timing and form of fertilizer application. Areas of the state where fall nitrogen applications are effective management will likely shift, particularly with urea fertilizer. With soils remaining above 50°F later into the fall season, fields are prone to nitrogen loss and subsequent water quality impacts following nitrogen applications.[23]
- Reductions in soil frost days will likely constrain the ability of loggers to access forest resources and constrain the winter season harvest.[12]

### Growing Conditions

- By mid-century, under higher emissions, the optimal growing region for corn and soybean is likely to shift both north and west, with more suitable growing conditions emerging in Minnesota and the Dakotas compared to Illinois and Iowa.[26] However, while models suggest that yields may increase initially from the changing climate, they may in fact begin to decline by mid-century.[27,28] Soil productivity will prove to be an important variable in any potential range shift.[26]
- Models also suggest that corn, soybean, & wheat yields decline at temperatures above 30°C (86°F). Thus, with more days at or above 86°F projected across all scenarios (Table 2), the risk of yield declines from extreme temperatures increases.[29]
- Warming is expected to increase the severity and frequency of crop and animal diseases.[25]
- Elevated overnight temperatures affect corn development and vegetable crops, negatively impacting yields.[19]
- Research suggests warm and dry years narrow the area with optimal growing conditions for corn while soybean has a higher tolerance for heat.[26]

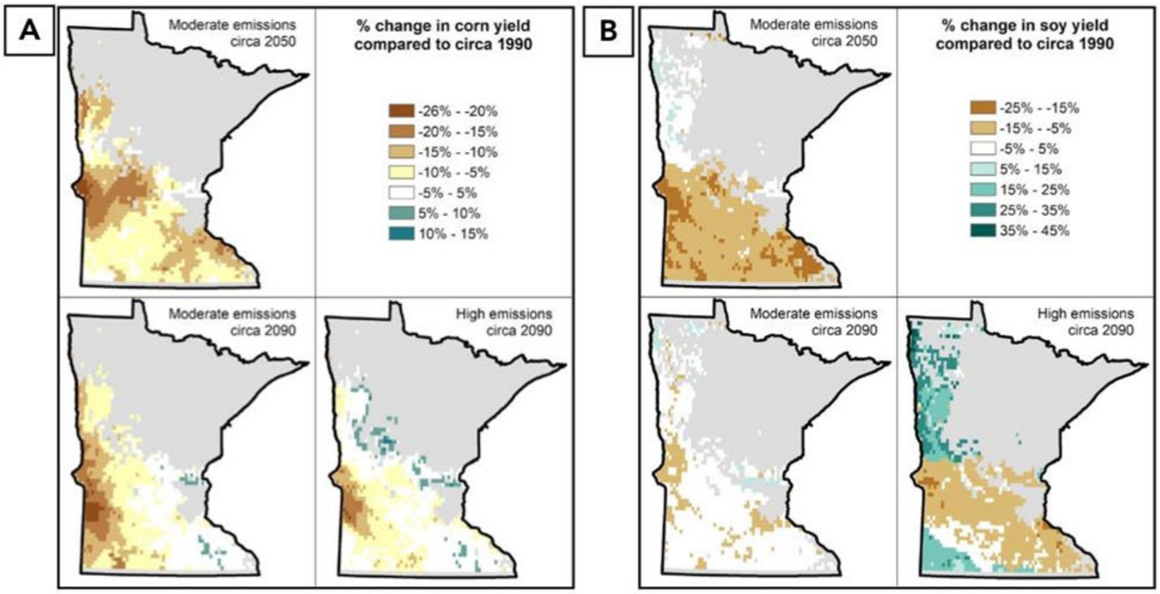


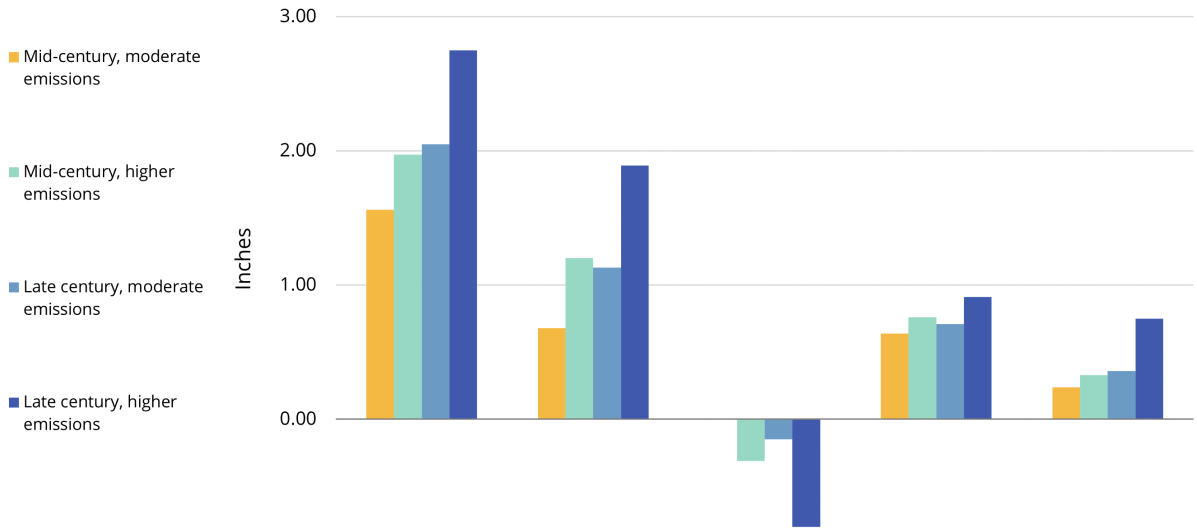

*Figure 2. Projected change in a) corn and b) soybean yield compared to circa 1990 levels for moderate and higher emissions for mid- and late century in Minnesota (RCP4.5 and 8.5, respectively). Maps modified from Noe et al., 2019.*[28,30]

## Adaptation Options

- Integrate alternative crop species via conservation crop rotations to maintain or improve soil health.[30]
- Choose crop species or varieties that are more suited to future conditions including heat tolerance and water stress.
- Consider double cropping systems to take advantage of the longer growing season.
- Utilize cover crops and/or reduce tillage to bolster soil health and increase water-holding capacity.
- Choose longer maturity corn cultivars to take advantage of longer growing season (potentially increasing yields), or plant shorter maturity corn varieties earlier in the season to avoid reproductive stages happening during worst risk of drought in later summer (likely to give average, but more consistent yields).[31]
- Be prepared with farming strategies that help manage too much soil moisture in the spring (such as cool season cover crops or improved drainage) and not enough soil moisture during late summer (such as high-cover crop residue systems, drainage water recycling, or controlled drainage structures).
- Consider on-farm water storage systems to carry water over from excess to deficit moisture conditions.
- Explore options related to agroforestry practices, such as windbreaks and alley cropping, which provide shade and can buffer crops and livestock from increasing heat.[31]
- Explore new forest products markets that utilize trees more accessible during shorter and wetter winter harvest seasons.[10]
- Explore options to reduce forest and farmworkers' exposure to high temperatures like providing shade, improved personal safety equipment, access to drinking water, and alternative working hours.[20]

## Precipitation

Annual precipitation is expected to increase in the future, with the largest seasonal increases likely during fall and spring. Decreases in total precipitation and greater variability are projected during the summer.[15] These projected changes are larger under the higher emissions scenario and for the late 21st century (2080-2099) (Figure 3).




| | Annual | Spring | Summer | Fall | Winter |
|---|---|---|---|---|---|
| Mid-century, moderate emissions | 1.56 | 0.68 | 0.00 | 0.64 | 0.24 |
| Mid-century, higher emissions | 1.97 | 1.20 | -0.31 | 0.76 | 0.33 |
| Late century, moderate emissions | 2.05 | 1.13 | -0.15 | 0.71 | 0.36 |
| Late century, higher emissions | 2.75 | 1.89 | -0.8 | 0.91 | 0.75 |

*Figure 3. Projected precipitation changes for Minnesota, annually and seasonally, in inches based on two different emission scenarios (moderate emissions (RCP4.5) and higher emissions (RCP8.5)).*[28,30]

### What Does This Mean for Agriculture?

- Winter and spring increases in precipitation can potentially lead to further loss of field and forest workdays, impaired root growth and function, and prolonged field wetness.[19]
- Wetter pastures and paddocks increase susceptibility to animal foot diseases and may impact livestock nutrition maintenance schedules and gestational weight.[32,33]
- Reduced or more irregular precipitation may decrease vegetable yields and quality. Research suggests that soluble solids and specific weight may increase in some crops.[34]
- Decreased soil moisture in summer will likely lead to greater crop irrigation demand.

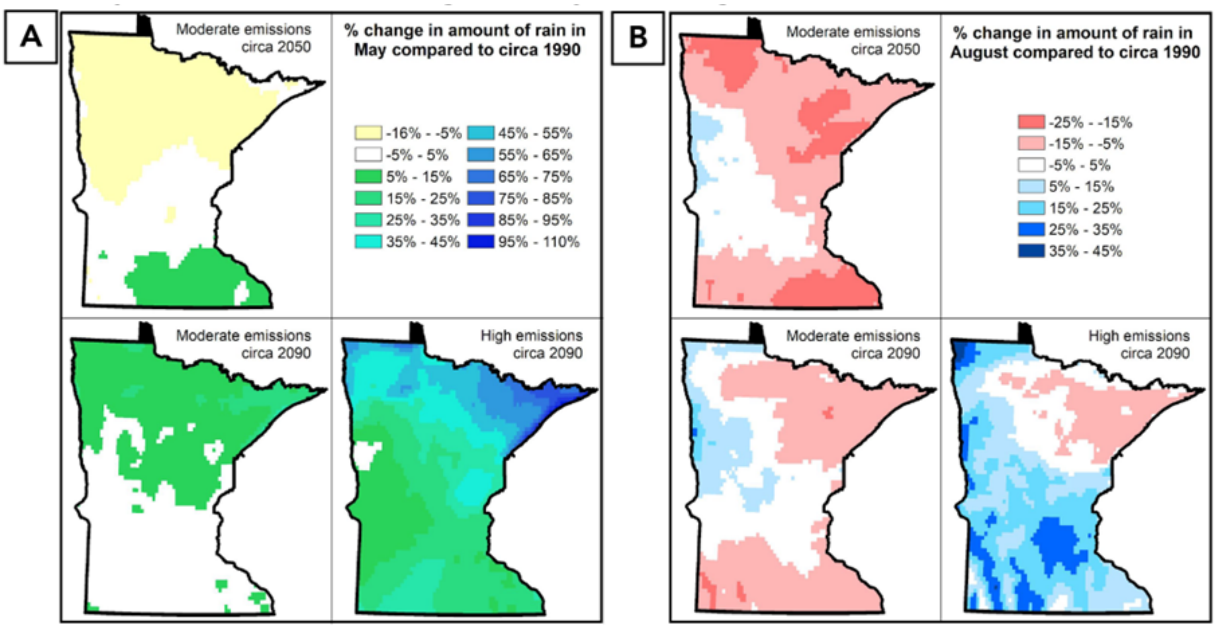



*Figure 4. Projected change in the amount of total monthly rainfall in a) May and b) August compared to circa 1990 levels for moderate and higher emissions scenarios in mid- and late century in Minnesota (RCP4.5 and 8.5, respectively). Maps modified from Noe et al., 2019.[28,30]*

## Adaptation Options

- Consider planting earlier in the season, which may be possible due to an increased growing season length in parts of Minnesota (Figure 5) due in part to an earlier last frost date.[30]
- Utilize cover crops and/or reduce tillage to bolster soil health and increase water-holding capacity.
- Use filter strips or riparian buffers in areas prone to flooding.[35]
- Increase soil health by improving soil structure and organic matter content to be better able to infiltrate precipitation, increase water-holding capacity, and maintain plant-available water during periods of dryness. Management to improve soil health can reduce risk of climate-related impacts as well as improve productivity.[19] Options include conservation crop rotations, cover crops, and reduce tillage.

*Farm field erosion driven by flooding in the northern Midwest. USDA Flickr.*

## Growing Season Length

Trends in growing season length across Minnesota since 1950 are variable across the state (Figure 5). Many counties have seen an increase of one to a few days per year per decade. Counties in northern and east central Minnesota have experienced statistically significant increases in growing season length, whereas many counties in the southern half of the state have not experienced significant change. This is a result of later first frosts in the fall and an earlier onset of frost-free conditions in spring.

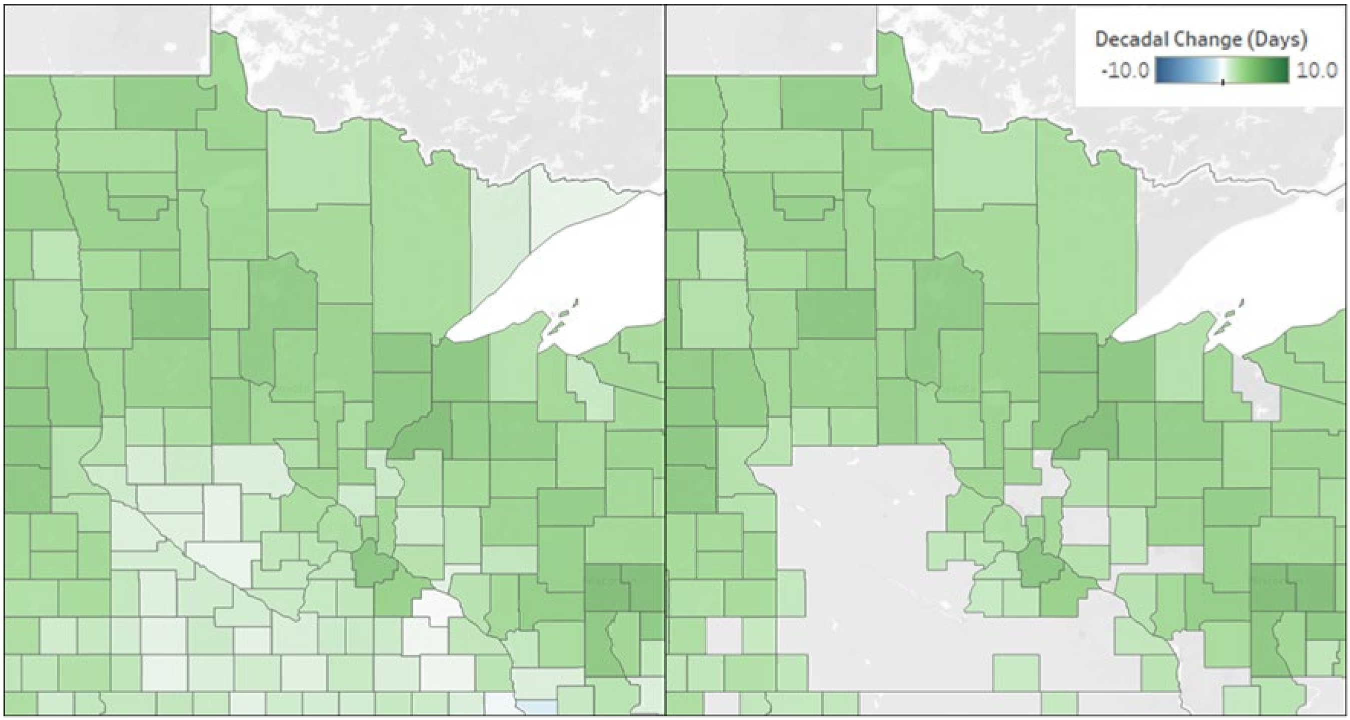



*Figure 5. Observed changes in average annual growing season length for Minnesota counties, 1950-2021. The right-hand image displays only those counties with a statistically significant trend ($p < 0.05$). Image source: Freeze Date Tool, Midwestern Regional Climate Center.*

### What Does this Mean for Agriculture?

- Pests, diseases, and weeds may expand their ranges. Additionally, the number of pest generations per season may increase, resulting in a greater impact on forests, crops, or livestock. An increased need for chemical treatments to address these impacts may lead to greater pesticide and herbicide resistance and greater input costs for farmers. Increased tree loss due to pest damage may increase wildfire risk.
- Longer growing season length may provide additional time for agricultural harvest and other end-of-season processes. Also, cover crops may experience increased post-harvest growth. These processes will be heavily influenced by fall soil moisture trends. However, it may reduce the winter forestry harvest period and drive changes in forest composition.
- Warmer winters increase risk of spring freeze injury by accelerating development of buds.
- Warmer winter temperatures may mean that chill hours for fruit crops are not met.[19]
- Later first frosts in the fall and earlier frost-free conditions in spring may shorten the winter harvest timber period, as well as making it more difficult to harvest some species that primarily inhabit wetter habitats.[12]

### Adaptation Options

- Plant agricultural crops earlier in the spring or consider options for double cropping.[35]
- Address pest, weed, and disease issues by diversifying crop rotations, enhancing use of Integrated Pest Management (IPM) techniques, and planting species and varieties that are resistant to pests and disease.[36]
- Consider planting fruit species and varieties which require fewer chilling hours, while keeping in mind the potential risk of trees and shrubs breaking dormancy during late-winter warm spells.
- Incorporate a diversity of species, such as in agroforestry systems, to spread biological and financial risk and create habitat diversity to promote beneficial insects and pollinators.[32]
- Develop and utilize forest harvest strategies that accommodate shorter soil freeze periods.[36,37]

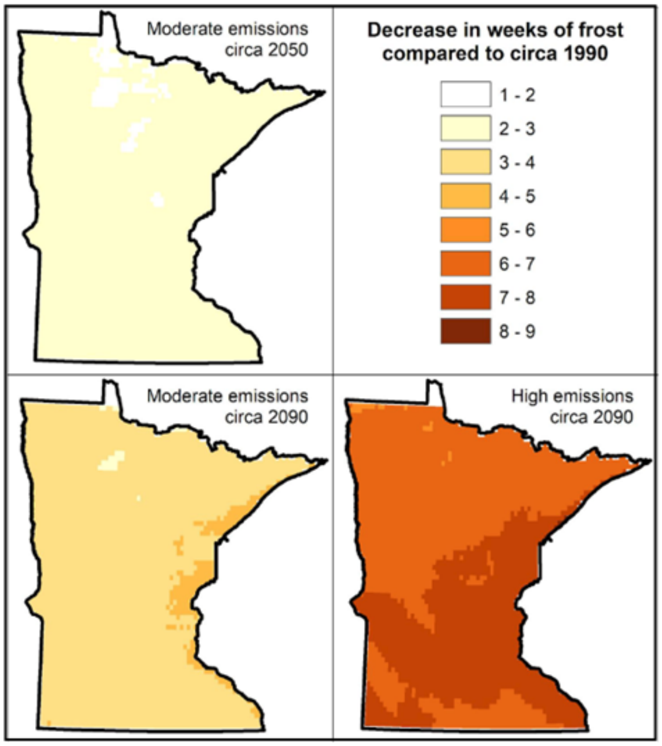



*Figure 6. Projected decrease in the number of weeks of frost compared to circa 1990. Maps modified from Noe et al., 2019.[28,30]*

## Relative Humidity

Despite increased water vapor in the atmosphere and precipitation, uncertainty remains in whether current trends of relative humidity will continue. This uncertainty is due to relative humidity's dependence on both air temperature and absolute moisture content in the air. Warmer temperatures would decrease relative humidity, and larger increase in absolute moisture content would increase relative humidity. Models indicate that relative humidity is projected to increase in spring and winter and decrease in the summer. However, if minimum (nighttime) temperature trends continue to outpace maximum (daytime), vapor pressure deficits will not increase, and relative humidity will stay higher.

### What Does this Mean for Agriculture?

- If relative humidity decreases:
  - Plants will be more prone to wilting and stunted growth.
  - Certain animal respiratory viruses may have a longer survival duration.[38]
  - Tree mortality may increase, especially for younger trees.[39]
- If relative humidity increases:
  - Wetness duration may increase leading to enhanced disease potential for crops.[40]
  - Plants will have less ability to evaporate water (part of the transpiration process) or take nutrients dependent on the flow of water from the soil.[41]

### Adaptation Options

- Plant varieties adapted to a higher variability of moisture (both wetter and drier climates) if available (including crops, pasture grasses, and tree fruit).[36]
- Use of mulch, cover crops, no-till, or reduced tillage to retain soil moisture and reduce soil temperatures during the summer.[36]
- Where appropriate, the establishment of trees to reduce evaporative water loss from the soil surface. Additionally, soils within agroforestry systems are better able to infiltrate and store water, which will be critically important in climates with warmer, drier summers.[32]

# Minnesota Climate Change Resources and Extension Programs

Minnesota universities and government agencies have a variety of resources and programs available to help agricultural and forestry audiences learn more about climate change, potential impacts on agriculture and forestry, and find support for adapting to the changing climate.

The University of Minnesota Climate Adaptation Partnership (MCAP) conducts cutting edge climate research and supports climate resilience actions across agriculture and natural resources sectors. The MCAP website – https://climate.umn.edu - provides access to information about Minnesota's changing climate, as well as interactive tools and statewide maps showing projected climate changes across Minnesota relevant to different sectors (https://app.climate.umn.edu/). MCAP also offers a range of training courses and technical assistance for climate-smart planning and decision-making. Currently, with support from the State of Minnesota and the Minnesota Corn Growers Association, MCAP is designing a range of dedicated 'climate smart' agricultural resources and educational programs.

The Minnesota Board of Soil and Water Resources (bwsr.state.mn.us) maintains a list of programs and funding opportunities that are available to assist with projects to enhance the climate resilience of agricultural and forest lands. The Minnesota Department of Agriculture is also piloting a Climate Smart Farms Project as part of the Minnesota Agricultural Water Quality Certification Program (MAWQCP; www.mda.state.mn.us/environment-sustainability/minnesota-agricultural-water-quality-certification-program) where certified farmers and agricultural landowners can receive a Climate Smart Farm Endorsement and funding to help implement management practices that strengthen climate resilience.

Other Minnesota climate change resources include:

- University of Minnesota Extension – www.extension.umn.edu
- Minnesota State Climate Office (DNR) – www.dnr.state.mn.us/climate
    - Decision Support Tools - www.dnr.state.mn.us/climate/agwx/decision_support.html
- Minnesota's Climate Action Framework – climate.state.mn.us/minnesotas-climate-action-framework

IMPORTANT: Please note that the datasets used to calculate the values in this paper may differ from those used in other Minnesota climate analyses. Be aware of this when comparing values across sources.

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