Climate Change Impacts on Indiana Agriculture

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Methods and Supplementary Materials

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

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Climate Change Impacts on Indiana Agriculture

Agriculture is a critically important aspect of economic and social life across Indiana. As of the 2022 Census of Agriculture, the state has approximately 53,600 farms with a total of 14.6 million acres of farmland.[1] In 2022, the market value of agricultural products sold totaled more than $18 billion, which ranks 9th nationally.[1] Indiana ranks 5th in the nation for grain production, with the common grain crops being corn, soybeans, and wheat.[1,2] Indiana is also national leader in ethanol and biodiesel production, ranking #6 in gallons of ethanol produced in 2022.[3] Livestock production is focused on hogs/pigs ($1.9 billion, ranked 6th), poultry/eggs ($2.6 billion, ranked 10th), equine ($50 million; ranked 9th), and milk ($1.1 billion, ranked 15th).[1] Indiana is also a state with a strong specialty crop industry. Fruit & tree nuts bring in $25.3 million annually, and vegetables bring in another $223.6 million as of 2022.[2]

Like other regions in the United States, agricultural productivity in Indiana is vulnerable to weather and climate variability. In recent decades, changes in Indiana'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 sectors extend beyond physical impacts to farms but also bring direct and indirect impacts to the overall cultural, social, and economic resilience of Indiana's communities. Therefore, when considering impacts on the agricultural sector in Indiana, climate change-driven stressors and disruptions can emerge well outside the geography of the state, nationally and internationally.

Observed Changes to Indiana's Climate

Observational changes in Indiana'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, the Great Lakes CAP/RISA Team (GLISA).[4] A summary of the recent historical, observed changes in Indiana's climate are described as follows:

Temperature

- Average annual temperature increased by 2.0°F between 1979 and 2021.
- Seasonal temperatures increased across all seasons.
- The change in average temperature between 1979 and 2021 was most extreme in the winter months (+2.1°F) and least extreme during the summer months (+0.8°F).
- Since the late 1800s, minimum temperatures have increased at a faster rate than maximum temperatures for all seasons. Winter minimum temperatures have increased at the most rapid rate (+0.3°F/decade).[5]

Precipitation

- Average annual precipitation has risen by 7.3" between 1979 and 2021, with the greatest increases observed during the winter (2.8") and summer (2.1").
- Extreme precipitation events (>2.0") have become more frequent, with an increase of 1.7 days annually between 1979 and 2021.
- The wettest five-year period in Indiana state history was 2015–2019, averaging 47.2 inches per year.[6]
- Great Lake levels have risen quite substantially in recent years; a new record was set in 2020, reaching the highest levels since 1886.[6]

Table 1. Observed changes in Indiana's climate based on data from 1979 to 2021. Change represents the linear trend in the observed climate variable between 1979 and 2021.

	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	52.3 °F	+2.0 °F	73.0 °F	+0.8 °F	54.1 °F	+1.8 °F	29.9 °F	+2.1 °F	52.0 °F	+1.9 °F
Precipitation	43.6"	+7.3"	12.7"	+2.1"	10.2"	+0.5"	8.3"	+2.8"	12.4"	+2.0"
Vapor Pressure Deficit*	6.1 mb	+0.7 mb	9.8 mb	+1.4 mb	6.2 mb	0 mb	2.0 mb	0 mb	6.4 mb	0.3 mb
Extreme precipitation (days with 2+" per year)	1.0 days	+1.7 days**								
Growing Season Length (frost-free days per year)	182.5 days	+13 days								

*Vapor pressure deficit (VPD) is an important variable for plant physiology. A higher VPD means that plants will lose more water to the air and dry out more rapidly. See page 9 for more information on how VPD relates to changes in relative humidity.

**This value represents a linear increasing slope in days with extreme precipitation events between 1979 and 2021. The average number of days per year went from <1 day per year in 1979 to >1 day per year in 2021. The difference was 1.7 days per year between 1979 and 2021. 1.0 days per year is the average value of all years between 1979 and 2021.

Observed Impacts on Agriculture and Forestry

- Longer growing seasons and increased temperature provide opportunities to plant alternative varieties of crops and trees.
- Shifting plant hardiness zones, due to increases in the average annual minimum temperatures.
- Increased crop water demand in recent decades, due largely in part to rising temperatures.
- There is some push-pull between increasing humidity (reduces demand) and increasing temperatures (increases demand). Over the past 30-40 years, the trend has been towards increasing evaporative demand in the Great Lakes region.[7,8]
- Greater frequency of heat stress (from heat and humidity) on trees, crops, livestock, and farmworkers.[9,10]
- Increased risk of damage from extreme events, including drought, severe storms, and 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, as well as affect insect and pathogen survival.
- Late freeze events are still possible despite a trend towards earlier last spring freeze dates.[11]
- Higher production costs and lower yields for some crops.[12,13]
- Elevated overnight lows can increase corn respiration rates and shorten the grain filling period, both of which lead to a reduction in yield.[14,15,16]
- Wetter soils, resulting in delayed agricultural planting, higher erosion, and nutrient loss.

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.[4] Two possible futures are presented:

- an intermediate scenario in which greenhouse gas emissions peak around mid-century (RCP4.5) and then slowly decline; and
- a very high scenario in which emissions continue to rise throughout the 21st century (RCP8.5).[17]

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 Indiana can expect to see continued warming in the future, with fewer extremely cold nights, more very warm nights, and more very hot days per year (Figure 1, Table 2). Climate models project that annual average temperatures in Indiana will increase over historical baselines by 3.1°F to 7.9°F by mid-century (2040-2059) under a very high emission scenario, and increases may exceed 14.5°F by late century (2080-2099) under the same scenario. It is also projected that the duration of hot days (over 86°F) will increase by mid-century.[9]

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 Indiana's cold and hot-weather climatologies that could have important ramifications for agriculture and forestry.

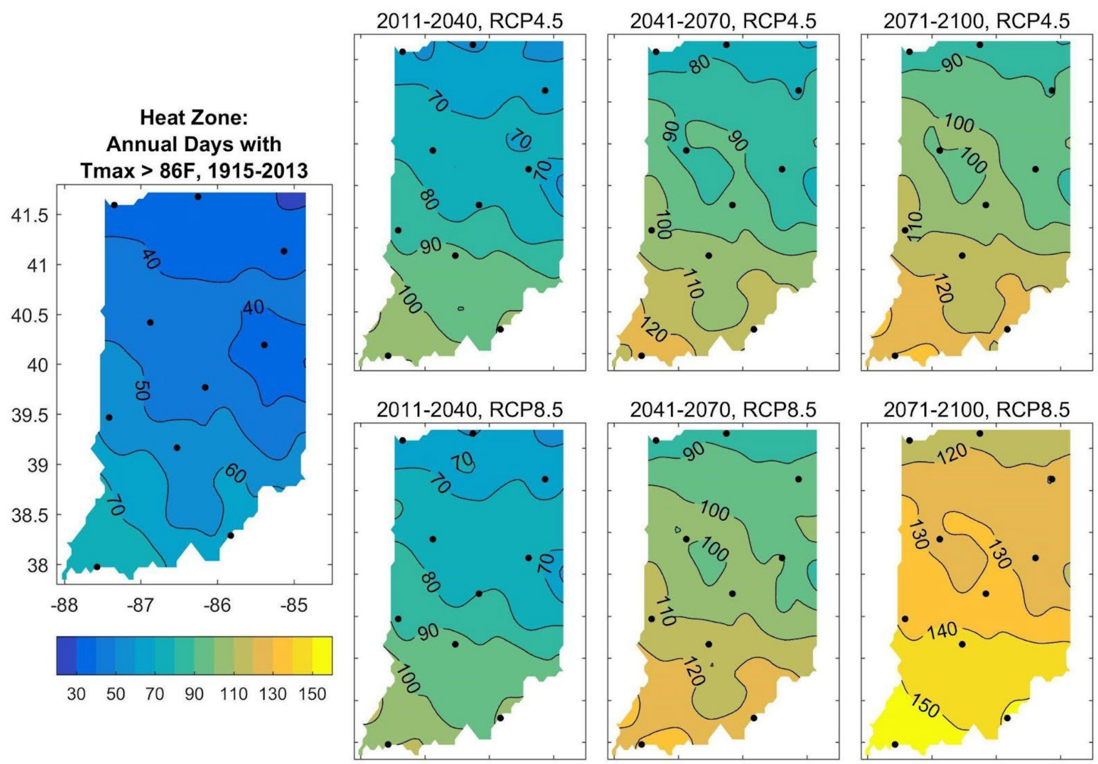


Figure 1. Maps of the historical & projected number of days per year with T_{max} above 86°F for a moderate (top) and very high (bottom) scenario.[9] The axes of the lefthand map denote the latitude (vertical axis) and longitude (horizontal axis).

Table 2. Modeled change (compared to the 1979 – 2005 period) in the number of days per year that meet or exceed a specified temperature threshold for Indiana. Included below the average change is the range of model projections.

	Low temp. ≤ 32°F	Low Temp. ≥ 80°F	High temp. ≥ 86°F	High temp. ≥ 95°F
Mid-century, intermediate	-32.1 days *(-48.8 to -16.1)*	+1.0 days *(0.0 to 6.7)*	+82.8 days *(67.7 to 94.3)*	+12.8 days *(4.2 to 30.5)*
Mid-century, very high	-36.7 days *(-55.7 to -17.5)*	+3.0 days *(0.2 to 17.3)*	+89.8 days *(73.3 to 102.9)*	+20.6 days *(6.8 to 50.3)*
Late century, intermediate	-41.7 days *(-56.8 to -21.8)*	+3.2 days *(0.0 to 16.3)*	+90.9 days *(73.5 to 108.3)*	+21.0 days *(4.1 to 50.7)*
Late century, very high	-65.3 days *(-84.4 to -40.9)*	+22.2 days *(2.9 to 60.4)*	+115.3 days *(93.6 to 132.6)*	+58.8 days *(23.5 to 101.1)*

What Does This Mean for Agriculture and Forestry?

Heat

- Increased heat stress (from heat and humidity) 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.[12,18,19,20]
- Farmworkers who work predominantly outdoors are also particularly vulnerable to heat-related illness.
- 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 about these impacts remains.[12,20] Crop genetics and field management will be key to mitigating these potential yield losses.
- Increased soil temperatures affect the appropriate timing and form of fertilizer application.
  - With soils remaining above 50°F later into the fall season and potentially early in the spring, fields are prone to nitrogen loss and subsequent water quality impacts following nitrogen applications.[22]
  - Areas of the state where fall nitrogen applications are effective management will likely shift to spring and/or in-season application timings.

Growing Conditions

- Warming can be expected to have meaningful impacts on pests in Indiana, through:
  - Reductions in winter kill for important pests.
  - Increases in the reproductive rates and capacity of insect pests.
  - Range expansions bringing new pests and natural enemies into the system.
- Warming can also be expected to increase the severity and frequency of crop and animal diseases.
  - Crops can become more susceptible to certain diseases (charcoal rot, pod & stem blight, etc.) when under stress.
  - Warming may also allow for pathogens more adapted to southern conditions to become more common in Indiana.
  - An increase in freezing/thawing cycles also will affect survival of organisms in the soil – for good or bad.
- Elevated overnight temperatures affect corn development and vegetable crops, negatively impacting yields.[20]
- High heat during the growing season may stress cool season crops like lettuce, broccoli, and cabbage.[20]
- Prolonged, extreme heat can impact "warm season" crops that still express the C_3 photosynthetic pathway like tomatoes and peppers by negatively impacting pollination at temperatures above 86°F.[23]

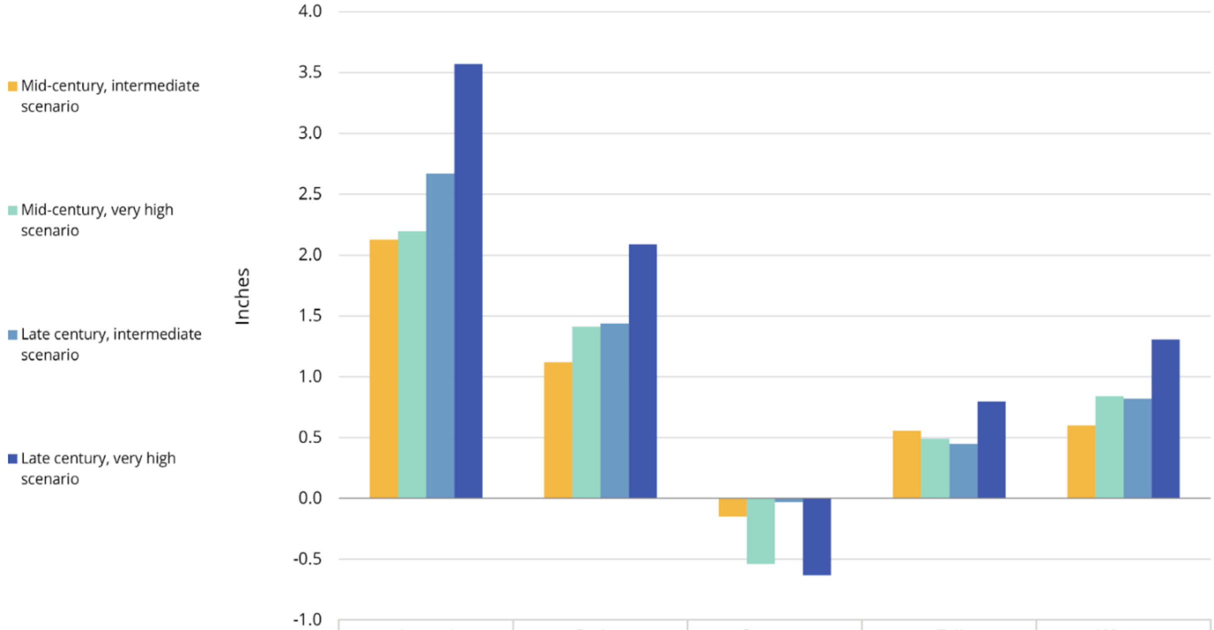
- Reduction in the nitrogen content of forages (grasses & legumes), a key quality for meat and dairy animal nutrition.[9]
- Northerly shifts in the optimal growing regions for corn and soybeans, with reductions in yield projected by models in Indiana.[24]
    - There is high model confidence in corn yield reduction. There is more uncertainty in soybean yields by late century.

Adaptation Options

- Utilize conservation practices, such as cover crops and/or reduced tillage, to increase infiltration and water holding capacity while building soil resilience and aggregation.
    - Conservation cropping systems that improve soil health and provide more soil cover (living cover or residues) help to keep more water in the soil (absorbs heat and keeps soils cooler in summer) and reduce daily soil temperature fluctuations.
- Choose crop species or varieties that are more suited to future conditions including heat tolerance and water stress.
- 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).[25]
- Consider the use of high tunnels in smaller-scale plots to moderate plants' exposure to extreme temperatures.
- Explore options to reduce farmworkers' exposure to high temperatures like providing shade, improved personal safety equipment, access to drinking water, and alternative working hours.
- Monitor for pathogens or insect pests that are currently found further south. Have a conversation with your advisor(s) about what pests may be an issue in the current growing season.

Precipitation

Annual precipitation is expected to increase in the future, with the largest seasonal increases likely during spring. Decreases in total precipitation and greater variability are projected during the summer. These changes are stronger under the very high scenario and for the late 21st century (2080-2099) (Figure 2).



	Annual	Spring	Summer	Fall	Winter
Mid-century, intermediate scenario	2.13 (5%)	1.12 (9%)	-0.15 (-1%)	0.56 (6%)	0.60 (7%)
Mid-century, very high scenario	2.20 (5%)	1.41 (12%)	-0.54 (-4%)	0.49 (5%)	0.84 (10%)
Late century, intermediate scenario	2.67 (6%)	1.44 (12%)	-0.03 (-0.3%)	0.45 (5%)	0.82 (10%)
Late century, very high scenario	3.57 (8%)	2.09 (18%)	-0.63 (-5%)	0.80 (8%)	1.31 (16%)

Figure 2. Projected precipitation changes for Indiana, annually and seasonally, in inches based on two different emission scenarios (intermediate (RCP4.5) and very high (RCP8.5)).

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.[9,26]
- Winter and spring increases in precipitation will lead to further loss and variability in the amount of field workdays per year, impaired root growth and function, and prolonged field wetness.[20]
- Wetter pastures and paddocks increase susceptibility to animal foot diseases and may impact livestock nutrition maintenance schedules and gestational weight.[27,28]
- Lower soil moisture, along with higher temperatures, are projected to substantially reduce corn (16-20%) and soybean (9-11%) yields in Indiana.[9]
- Decreased soil moisture in summer will likely lead to greater crop irrigation demand.
- Increasing spring and winter precipitation will lead to an increase in spring subsurface flow from tile drains; expected to increase by 30-50% by mid-century in Indiana.[9]

Adaptation Options

- 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 residue systems, drainage water recycling, or controlled drainage structures).

- Consider implementing water retention basins to capture water during periods of excess moisture to be used as irrigation water during dry periods.
- In tile drain systems, consider putting gates in the field tile outlets to retain moisture in fields during dry periods.
- Consider planting earlier in the season with an earlier last frost date, which may be possible in years where the soil moisture conditions in the field are not too wet.[25]
- Implementing strategies to improve soil health. Increasing soil health by improving soil structure and organic matter content will enable the soil to be better able to infiltrate precipitation, increase water-holding capacity, and maintain plant-available water during periods of dryness.[20] Options include conservation crop rotations, cover crops, and reduced tillage.
- Consider 'redefining the field edge' in perennially flood prone areas by replacing row crops with perennial grasses for haying/grazing or native mixes.[29,30]
- Consider investing in equipment and/or technologies that reduce soil compaction and optimize planting (e.g., tire configuration/width, tracks, controlled field traffic patterns) in shortened planting windows.

Growing Season Length

Growing season trends across Indiana since 1950 are variable across the state (Figure 3). Many counties have seen an increase of one to a few days per decade; counties with a statistically significant increase in growing season length are in the southern, eastern, and north-central regions. This is a result of later first frosts in the fall and an earlier onset of frost-free conditions in spring. With the warming winters, it is also projected that plant hardiness zones (based on the lowest temperatures reached annually) in Indiana will trend warmer (Figure 4). This is relevant for overwintering perennial crops, such as fruit trees.

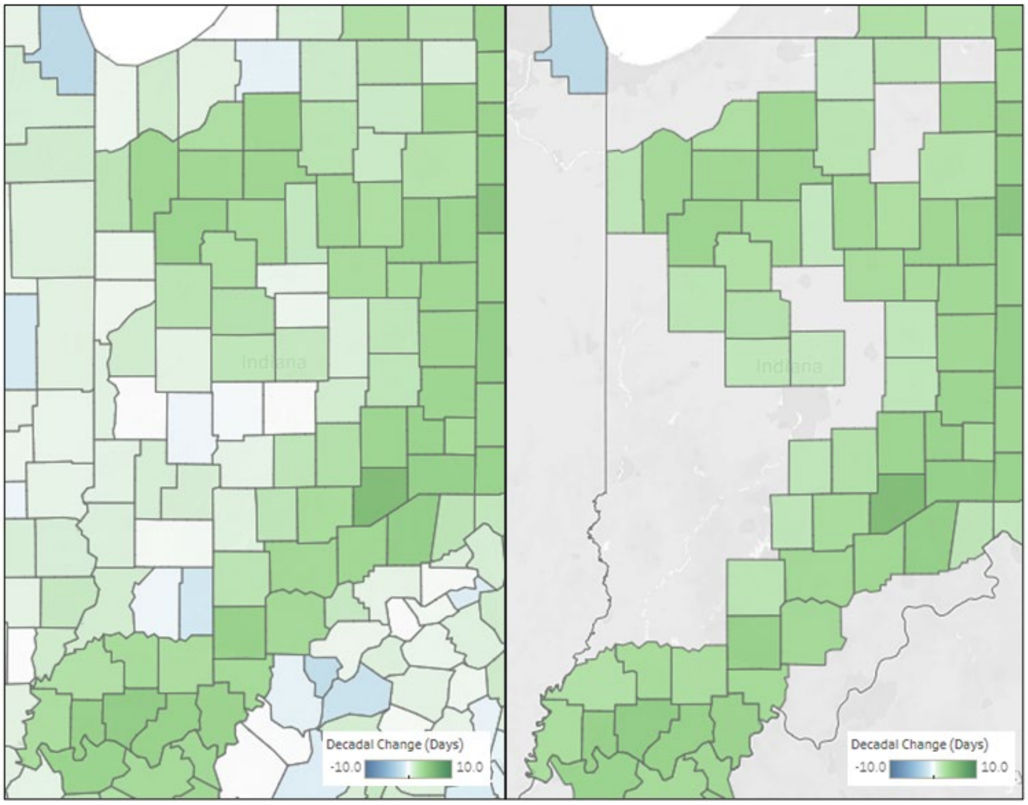


Figure 3. Historical changes in average annual growing season length for Indiana counties, 1950-2023, based on gridded Applied Climate Information System dataset. The right-hand image displays only those counties with a statistically significant trend ($p<0.05$).[11] Image source: Freeze Date Tool, Midwestern Regional Climate Center, https://mrcc.purdue.edu/freeze/freezedatetool.html. Original data source is https://www.rcc-acis.org/.

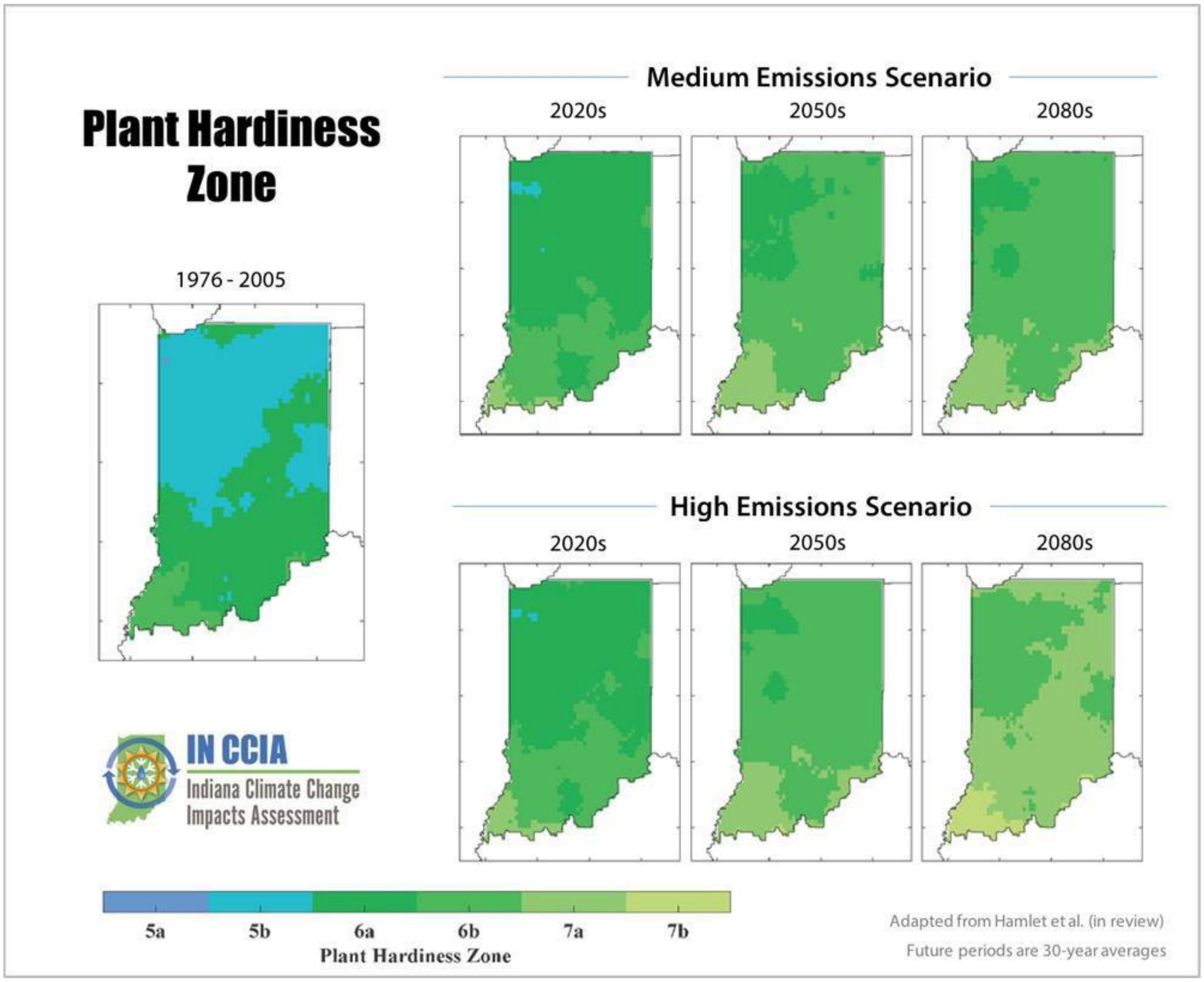


Figure 4. Historical & projected changes in the plant hardiness zones (based on the coldest minimum temperatures experienced annually) for a medium (top) and high (bottom) emission scenario.[9]

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.
- Pests, diseases, and weeds may expand their ranges. Additionally, the number of pest generations per season may increase, resulting in a greater impact on crops or livestock.
- An increased need for chemical treatments to address these impacts may lead to greater pesticide and herbicide resistance, greater input costs for farmers, and greater environmental exposure to these chemicals.
- Integrated Pest Management (IPM) strategies, such as habitat modification and biological controls, can serve as alternative methods to chemical treatment or can be implemented alongside chemical treatments.
- 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, such as increased post-harvest cover crop growth.
- Double cropping may become more viable in Indiana with longer growing seasons.
- Warmer winters increase risk of spring freeze injury by accelerating the deacclimation from dormancy.

- Chilling hours for fruit are projected to decrease in the southern portion of Indiana with warming winters. This may lead to chilling hour requirements not being met for certain fruit species/varieties.[9,31]
- In years where the chilling hour requirement has been met and there is early spring warmth, buds may break before the risk of a freeze has passed. The earlier timing of budbreak will make plants more susceptible to freeze damage.[20]
- 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.

Adaptation Options

- Plant agricultural crops earlier in the spring (if soil conditions are favorable) or consider options for double or relay cropping.[29]
- Address pest, weed, and disease issues by diversifying crop rotations, enhancing use of IPM techniques, and planting species and varieties that are more adapted to changing conditions.[29]
- Consider planting fruit species and cultivars with a lower chilling hour requirement with the projected decrease in annual chilling hour accumulation. However, bear in mind that this could lead to trees blooming earlier in years with a warmer spring, exposing the fruit to frost/freeze damage.

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. A larger increase in temperature would decrease relative humidity, and a larger increase in absolute moisture content would increase relative humidity. Models indicate that relative humidity is projected to decrease annually and across all seasons in Indiana. 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. [32]
- Tree mortality may increase, especially for younger trees.[26]

If relative humidity increases:

- Wetness duration may increase leading to enhanced disease potential for crops.[33]
- Plants will have a decreased ability to evaporate water (part of the transpiration process) or take up nutrients dependent on the flow of water from the soil.[34]
- The ability for animals to utilize evaporative cooling will be reduced, increasing the effects of heat stress related health and performance issues.[35]

Humidity trends have major implications for crop water demand:

- If daily minimum temps (a good approximation of dew point temps) continue to outpace increases in daily maximum temps, vapor pressure deficits will not increase, and crop water demand will not increase.
- If daily minimum & maximum temps increase at a similar rate in the future, vapor pressure deficits can be expected to increase and crop water demand will subsequently increase.

Adaptation Options

- Plant varieties adapted to drier or wetter climates (or those that may withstand high variability) if available (including crops, pasture grasses, and tree fruit).[29]
- Use of mulch, cover crops, no-till, or reduced tillage to retain soil moisture and reduce soil temperatures during the summer.[18]
- Where appropriate, establish 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.[36]

Indiana Climate Change Resources and Extension Programs

- Farming 4 a Better Climate: https://ag.purdue.edu/indiana-state-climate/research/farming-for-a-better-climate/
- Indiana Climate Change Impacts Assessment: https://ag.purdue.edu/indianaclimate/agriculture-report/
- Conservation Cropping Systems Initiative Soil Health Podcast: https://www.ccsin.org/podcast
- Indiana State Climate Office: https://ag.purdue.edu/indiana-state-climate/
- Purdue Extension Entomology – Fruit: https://extension.entm.purdue.edu/fruit/
- Purdue Extension Entomology - Vegetables: https://extension.entm.purdue.edu/veg/
- Midwest Vegetable Guide: https://mwveguide.org/
- Purdue 4-H – Youth & Entomology: https://extension.entm.purdue.edu/radicalbugs/index.php?page=selecting_treatment_strategies

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