Climate Change Impacts on Missouri Agriculture

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Methods and Supplementary Materials

Please visit http://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 Missouri Agriculture

Agriculture is a critically important aspect of economic and social life across Missouri. As of the 2022 Census of Agriculture, the state has approximately 87,900 farms with a total of 27 million acres of farmland.[1] In 2022, the market value of agricultural products sold totaled more than $14.6 billion, which ranks 12th nationally.[1] Missouri ranks 10th in the nation for grain production, with the common grain crops being corn, soybeans, and wheat.[1,2] Missouri is also a national leader in hay production, ranking 3rd in the nation for tons produced (5.1 million).[2] Cotton is another major crop in Missouri, with sales of over $355 million in 2022 (7th in the US).[1,2] Livestock production is focused on hogs, poultry, cattle, and sheep/goats. Missouri is ranked 7th in the nation in hog and poultry/egg sales, 9th in cattle/calves, and 16th in sheep and goat products.[1,2] Missouri is also a highly forested state, containing over 15.4 million acres of forested land.[3] Forest products in Missouri bring $9.7 billion to the state's economy, with products being exported domestically and abroad.[3]

Like other regions in the United States, agricultural productivity in Missouri is vulnerable to weather and climate variability. In recent decades, changes in Missouri'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 Missouri's communities. Therefore, when considering impacts on the agricultural sector in Missouri, climate change-driven stressors and disruptions can emerge well outside the geography of the state, nationally and internationally.

Observed Changes to Missouri's Climate

Observational changes in Missouri'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 historical, observed changes in Missouri's climate are described as follows:

Temperature

- Average annual temperature increased by 1.6°F between 1979 and 2021.
- The change in average temperature between 1979 and 2021 was most extreme in the fall (1.6°F) and winter (1.4°F) months.
- Minimum temperatures have increased more than maximum temperatures. Since 1900, the rate of Missouri's minimum temperature increase is 1.4°F/century and the rate of maximum temperature increase is 0.3°F.[5]
- Since 1900, winter is the season in which minimum temperatures have increased at the most rapid rate (+2.3°F/decade) compared to other seasons.[5]
- Temperatures in summer warmed the least over this time period. However, there has been a notable increase in the frequency of very warm nights (minimum temp ≥75°F) since the late 1980s.[6]

Precipitation

- Average annual precipitation has risen by 5.2" between 1979 and 2021, with the greatest increases observed during the spring (3.9") and summer (2.6").
- A decrease in seasonal precipitation was observed in the fall months (-1.8").
- Extreme precipitation events (> 2.0") have become more frequent, with an increase of 2.0 days annually between 1979 and 2021.
- Most of the state experiences > 40% of its annual precipitation total on the 10 wettest days of the year.[6]
- Missouri's average annual dew point temperature has increased since 1979.

Table 1. Observed changes in Missouri's climate based on data from 1979 – 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	55.1 °F	+1.6 °F	76.0 °F	+0.8 °F	56.2 °F	+1.6 °F	32.8 °F	+1.4 °F	55.0 °F	+1.1 °F
Precipitation	43.5"	+5.2"	12.7"	+2.6"	10.7"	-1.8"	7.0"	+0.6"	13.1"	+3.9"
Vapor Pressure Deficit	7.4 mb	+0.2 mb	11.9 mb	+0.7 mb	7.3 mb	0 mb	2.9 mb	0 mb	7.4 mb	-0.2 mb
Extreme precipitation (days with 2+" per year)	1.5 days	+2.0 days								
Growing Season Length (frost-free days per year)	190.4 days	+16.3 days								

Observed Impacts on Agriculture

- Longer growing seasons and increased temperature provide opportunities to plant alternative varieties of crops and trees.
- Farmworker safety concerns with higher temperatures and humidity during the summer.[7]
- 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, as well as affect insect and pathogen survival.
  - Late freeze events are still possible despite a trend towards earlier last spring freeze dates.[8]
- Elevated temperatures in early spring impact the viability of production of cool-season crops in the spring, in some years reducing yields of cool-season crops.
  - More reliance on the fall planting window for growing cool-season crops.
- Higher production costs and lower yields for some crops.[9,10]
  - Elevated overnight lows can increase corn respiration rates and shorten the grain filling period, both of which lead to a reduction in yield.[11,12,13]
- Soil moisture models indicate a high degree of variability from year to year.[14] Years with wetter soils during the spring can result in delayed agricultural planting, higher erosion, and nutrient loss.
- Increased growing season evapotranspiration (ET).

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 (RCP 4.5) and then slowly decline, and a very high scenario in which emissions continue to rise throughout the 21st century (RCP8.5).[15] 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.

Temperature

All available climate model projections indicate that Missouri can expect to see continued warming in the future, with fewer extremely cold nights, more very warm nights, and more very hot days (Table 2). Climate models project that annual average temperatures in Missouri will increase over historical baselines by 2.6°F to 7.7°F by mid-century (2040-2059) under the very high emission scenario, and increases may exceed 13°F by late century (2080-2099) under the same scenario.

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

Table 2. Modeled mean change (compared to the 1979 – 2005 period) in the number of days per year that meet or exceed a specified temperature threshold for Missouri. Values are provided for mid- and late-century and for two future scenarios of projected climate change. Included below the average change is the range of all model projections that make up the modeled mean change.

	Low temp. ≤ 32°F	Low temp. ≥ 80°F	High temp. ≥ 86°F	High temp. ≥ 95°F
Mid-century, intermediate	-28.1 days *(-44.0 to -13.8)*	+2.5 days *(+0.35 to +7.0)*	+76.1 days *(+61.5 to +87.6)*	+23.3 days *(+10.1 to +38.8)*
Mid-century, very high	-32.0 days *(-46.8 to -16.3)*	+6.1 days *(+0.6 to +24.8)*	+82.5 days *(+66.7 to +93.5)*	+32.9 days *(+12.8 to +60.4)*
Late century, intermediate	-36.3 days *(-52.7 to -17.7)*	+6.2 days *(+0.4 to +18.5)*	+83.8 days *(+66.9 to +101.2)*	+33.0 days *(+11.2 to +56.3)*
Late century, very high	-59.0 days *(-75.1 to -32.5)*	+34.6 days *(+6.5 to +73.7)*	+108.0 days *(+85.4 to +124.6)*	+72.9 days *(+36.6 to +106.0)*

What Does This Mean for Agriculture and Forestry?

Heat Stress

- Increased heat stress severely impacts farmers and animals. Among livestock, high heat can decrease meat and milk quality and quantity, and egg production.[9,16,17,18]
- Farmworkers who work predominantly outdoors are also particularly vulnerable to heat-related illness.[7]
- The frequency of short-term and rapid onset drought during the summer is potentially higher due to warmer temperatures and increased precipitation variability.[19]
- Elevated overnight temperatures speed up corn development, reducing the length of the grain-filling period which negatively impacts yields.[18] Increased respiration rates during hot nights can also lead to reduced dry matter accumulation in corn.[11,12,13]

Soil Impacts

- Decreased soil moisture affects agricultural plant physiology, potentially leading to an increased risk of reduced yields or crop losses, but uncertainty about these impacts remains.[9,18] 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.[20]
- Areas of the state where fall nitrogen applications are effective management will likely shift (or have shifted) to spring and/or in-season application timings.

Growing Conditions

- Warming can be expected to have meaningful impacts on the prevalence of insects (invasive and native) in Missouri, through:
    - Reductions in winter kill for important pests, leading to earlier establishment in spring.
    - 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 Missouri.
    - An increase in freezing/thawing cycles also will affect survival of organisms in the soil – for good or bad.
- Northerly shifts in the optimal growing regions for corn and soybeans, with models projecting yield reductions.[21]
    - There is high model confidence in corn yield reduction. There is more uncertainty in soybean yields by late century.[21]

Specialty Crop Impacts

- Potential loss of chilling hours could reduce the number of types of fruit and varieties within a given fruit crop that are able to initiate bud formation. Established orchards could have lower yields if chilling hours decline, and varieties already established on a farm require more chilling hours than occur.
- Warmer summer temperatures can negatively impact ripening and quality of fruit crops.
- High heat during the growing season may stress cool season crops like lettuce, broccoli, and cabbage.[18]
- Prolonged, extreme heat can impact warm season crops like tomatoes and peppers by negatively impacting pollination at temperatures above 86°F.[22]
- Rate of change in climate exceeds perennial plant breeders ability to create new varieties adaptable to climate conditions.

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.[23]
- Work with your advisor(s) to select crop varieties and species that are well-suited for the conditions in your area, and that will be able to tolerate higher heat and increased water stress.
    - Consider 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).[24]

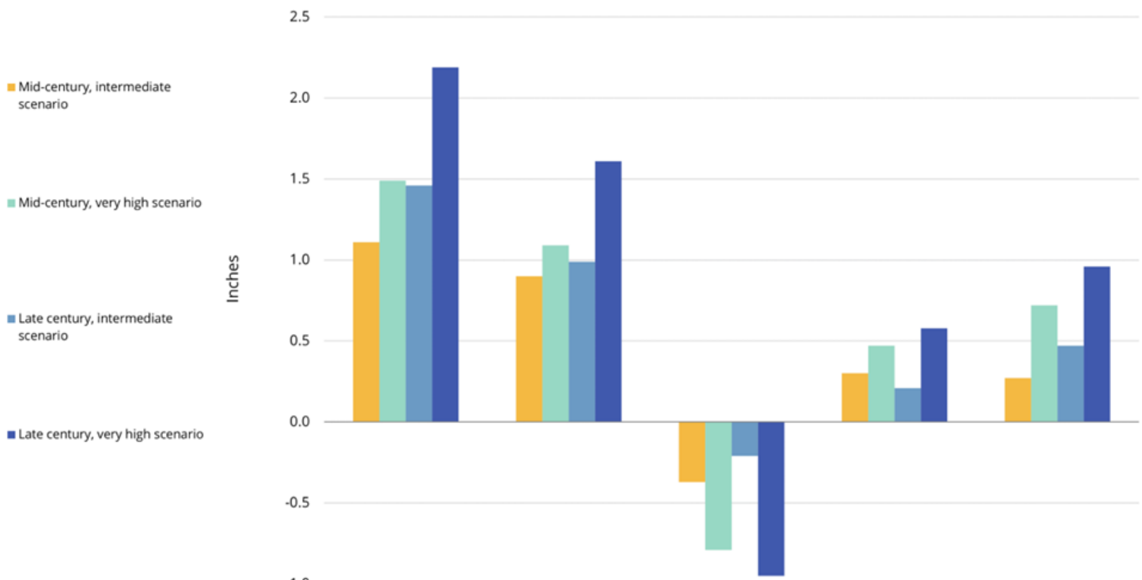
- Be prepared to enact farming strategies that manage excess soil moisture in the spring (such as cool season cover crops or improved drainage) and not enough soil moisture during late summer (such as high residue systems, drainage water recycling, or controlled drainage structures).
- Monitor for pathogens or insect pests that are currently found further south.

Specialty Crop Considerations

- Explore options to reduce farmworkers' exposure to high temperatures like providing shade, improved personal safety equipment, access to drinking water, and alternative working hours.
- Utilize white plastic mulch as an alternative to black plastic mulch to reduce surface air and soil temperatures.
- Utilize overhead irrigation to reduce temperatures in the micro-climate of growing zones of temperature sensitive plants.
- Consider the use of controlled environment agriculture to adapt to negative effects of climate change. For example, consider the use of high tunnels in smaller-scale plots to moderate plants' exposure to extreme temperatures.

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 larger under the very high scenario and for the late 21st century (2080-2099) (Figure 1). An increase in the frequency and severity of heavy precipitation events are also projected to increase by mid-century under continued emissions.[25]



	Annual	Spring	Summer	Fall	Winter
Mid-century, intermediate scenario	1.11 (3%)	0.90 (7%)	-0.37 (-3%)	0.30 (3%)	0.27 (4%)
Mid-century, very high scenario	1.49 (4%)	1.09 (9%)	-0.79 (-7%)	0.47 (4%)	0.72 (11%)
Late century, intermediate scenario	1.46 (3%)	0.99 (8%)	-0.21 (-2%)	0.21 (2%)	0.47 (8%)
Late century, very high scenario	2.19 (5%)	1.61 (13%)	-0.95 (-8%)	0.65 (6%)	0.96 (15%)

Figure 1. Projected precipitation changes for Missouri, annually and seasonally, in inches (with percent change in parentheses) 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 will lead to further loss of field workdays, impaired root growth and function, and prolonged field wetness.[18]
    - This could be somewhat offset by increases in potential evapotranspiration (i.e., water flux from soil/plants to the air) under a warmer climate.[26]
- When soils are wet during the spring, there is an increased risk of soil compaction from machinery traffic.

- An increase in spring runoff, due in part to increased precipitation, is projected for Missouri under a moderate emissions scenario.
- Decreased soil moisture in summer will likely lead to greater crop irrigation demand. However, this could be challenged by a lack of surface water during dry periods.
- Extended dry periods leading to reduced pasture conditions for livestock.
- Increase in wildfires in the continental US and Canada with increased fuel aridity (i.e., dry vegetation). Upper-level wind patterns could move smoke from fires outside of the Midwest over the Midwest.[27]
- Some studies suggest corn and soybean yield impacts from smoke coverage in the sky. However, there is uncertainty as to how yields will be impacted by future smoke events.[28]

Specialty Crop Impacts

- Delayed planting of seeds and transplants due to high early spring rainfall will delay harvest, reducing access to early season premiums for certain crops.
- Spring flooding could increase crop loss due to food safety regulations.

Adaptation Options

- Consider planting earlier in the season if soil moisture conditions allow, which may be possible due to small increases in field workability days in late March to early April, coupled with an earlier last frost date.[24]
- 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]
- 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.[18] Options include conservation crop rotations, cover crops, and reduce tillage.
- Cover cropping can help remove excess moisture from poorly drained soils prior to planting.
- Consider implementing water retention basins to capture water during periods of excess moisture to be used as irrigation water during dry periods.

Specialty Crop Considerations

- Prioritize irrigation in specialty crops to deal with low summer rainfall and higher evapotranspiration.
- Increase use of field drainage techniques including raised beds, drainage tiling, & swales in specialty crop production.
- Sowing grasses/legumes into bed alleys to absorb field moisture and increase accessibility during post-rainfall events.

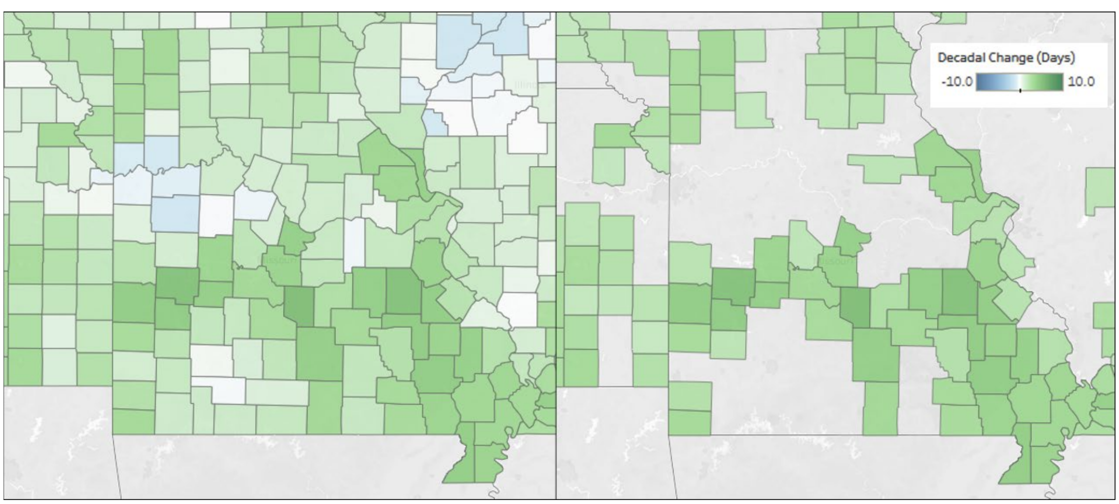


Figure 2. Observed changes in average annual growing season length for Missouri counties, 1950-2023, based on gridded Applied Climate Information System data. The right-hand image displays only those counties with a statistically significant trend ($p<0.05$). Image source: Freeze Date Tool, Midwestern Regional Climate Center, https://mrcc.purdue.edu/freeze/freezedatetool.html. Original data source is https://www.rcc-acis.org/.

Growing Season Length

Growing season trends across Missouri since 1950 are variable across the state but generally increasing (Figure 2). 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 scattered across the northern and southern parts of the state, as well as along the Mississippi River. This is a result of later first frosts in the fall and an earlier onset of frost-free conditions in spring.

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 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.
- 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. Both of these potential outcomes will be heavily influenced by fall soil moisture trends. However, a longer free-free period may reduce the winter forestry harvest period and drive changes in forest composition.
- Double cropping may become more viable in Missouri with longer growing seasons.
- 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.

Specialty Crop Impacts

- Warmer winters increase risk of spring freeze injury by accelerating the deacclimation from dormancy.
- Chilling hours for fruit have remained steady in Missouri in recent decades.[31] However, climate models project a decrease in chilling hours for most in the state with warming winters. Likewise, warming winters could result in more years with an earlier budbreak, which will make plants more susceptible to freeze damage.[29]
- Annual vegetable crops will have a longer production window, potentially increasing yields.
- Growers could try to plant vegetable crops earlier to take advantage of longer growing seasons, but bearing in mind that they still could be impacted by late frost.

Adaptation Options

- Plant agricultural crops earlier in the spring or consider options for double or relay cropping.[29]
- 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 more adapted to changing conditions.[29]
- Consider planting fruit species and cultivars which require fewer chilling hours to adjust to a projected decline in annual chilling hour accumulation. However, bear in mind the potential risk of trees and shrubs breaking dormancy during late-winter warm spells.

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. Larger increases in temperature would decrease relative humidity, and larger increases in absolute moisture content would increase relative humidity. Models indicate that relative humidity is projected to decrease annually in Missouri, particularly in 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 because of increased water use.
- Certain animal respiratory viruses may have a longer survival duration.[32]
- Increased irrigation demand in specialty crops.
- Tree mortality may increase, especially for younger trees.[33]

If relative humidity increases:

- Wetness duration may increase leading to enhanced disease potential for crops.[34]
- Plants will have less ability to evaporate water (part of the transpiration process) or take up nutrients dependent on the flow of water from the soil.[35]
- The ability for animals to utilize evaporative cooling will be reduced, increasing the effects of heat stress related health and performance issues.[36]
- Increased incidence of physiological disorders in crops produced in controlled environment agriculture systems, that negatively affect the quality and marketability of fruit and vegetable crops (i.e., tip burn in lettuce, blossom end rot in tomatoes).

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.[29]
- For specialty crop irrigation, optimize irrigation scheduling based on sensor data.
- 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.[37]

Missouri Climate Change Resources and Extension Programs

Missouri Climate Center (http://climate.missouri.edu/)

University of Missouri Extension (https://extension.missouri.edu/)

University of Missouri Extension Agriculture and Environment Programs (https://extension.missouri.edu/topics/agriculture-and-environment)

Missouri Frost / Freeze Probabilities Guide (https://ipm.missouri.edu/frostfreezeguide/)

MU Extension Drought Resources Program (https://extension.missouri.edu/programs/drought-resources)

MU Extension Irrigation Program (http://crops.missouri.edu/irrigation/)

MU High Tunnel Production Guide – Tomato (https://extension.missouri.edu/publications/m170)

MU High Tunnel Production Guide – Melons (https://extension.missouri.edu/publications/m173)

MU Extension Mulches Factsheet (https://extension.missouri.edu/publications/g6960)

Horizon Point (your farm location tied to local weather stations) (http://agebb.missouri.edu/horizonpoint/)

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