The Impacts of Shifting Climate on Midwest Agriculture

The United States produces, consumes and exports more corn than any other country. The US cultivates more soybeans than any country besides Brazil. Along with wheat, American production of these crops is critical to global food chains and the Midwestern region of the US is the center of their production.

If you've spent anytime driving around the Midwest, like me, this truth likely doesn't come as surprise. A 'short' five-hour drive from Chicago to Saint Louis doesn't provide much scenery besides fields of corn and billboards. But despite being surrounded by submerged in a sea of farmland, it is easy to overlook the significance the production of fields crops in the regional and global food supply.

Another topic you are likely to hear a lot about in the Midwest is weather. Irrespective of the use of weather for low-level small talk, agricultural communities tend to have particularly acute focus on the subject given the sway it holds over many people's livelihoods. Droughts, heat waves, and cold snaps all have the potential to induce financial pain on those who depend on their crop's success for their own wellbeing.

Given my roots in Midwest and my interest in climate change, I felt that this project would be a great space to build a deeper understanding how agriculture and climate change have impacted the region's economic and cultural keystone. Since the effects of climate change have already begun to manifest, I am using this project to explore how regional climate and agriculture in the Midwest have changed over the past half century.

Data

To do this, I've pulled county-level crop data from the National Agricultural Statistics Service from the past 48 years (1975 – 1980). I've combined this with county-level climate data from the NOAA, using data stretching back to 1950.

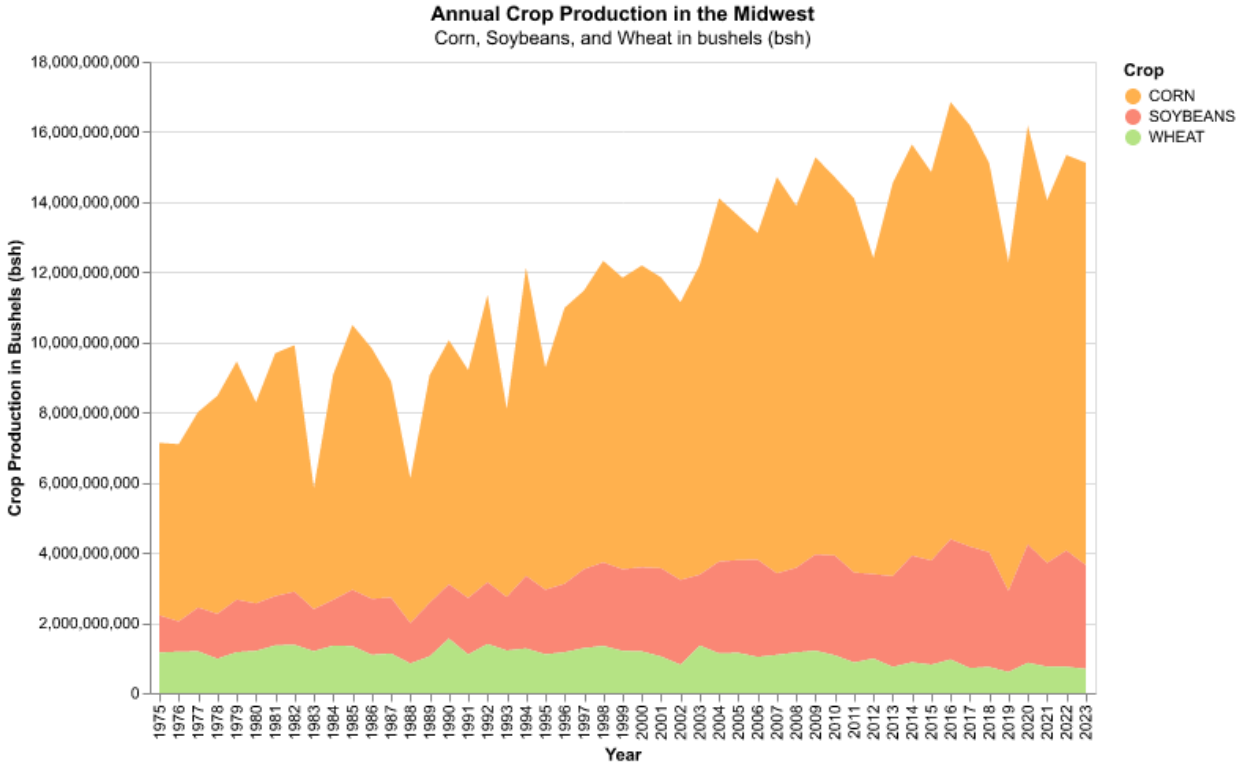
Field Crops in the Midwest

Regional Trends

Before digging into potential impacts of climate change, I want to better understand production of the three most important field crops in the region over the past 50 years: corn, soybeans, and wheat. Let's look at three different metrics to understand how regional agricultural production has changed.

Total Production (in bushels)

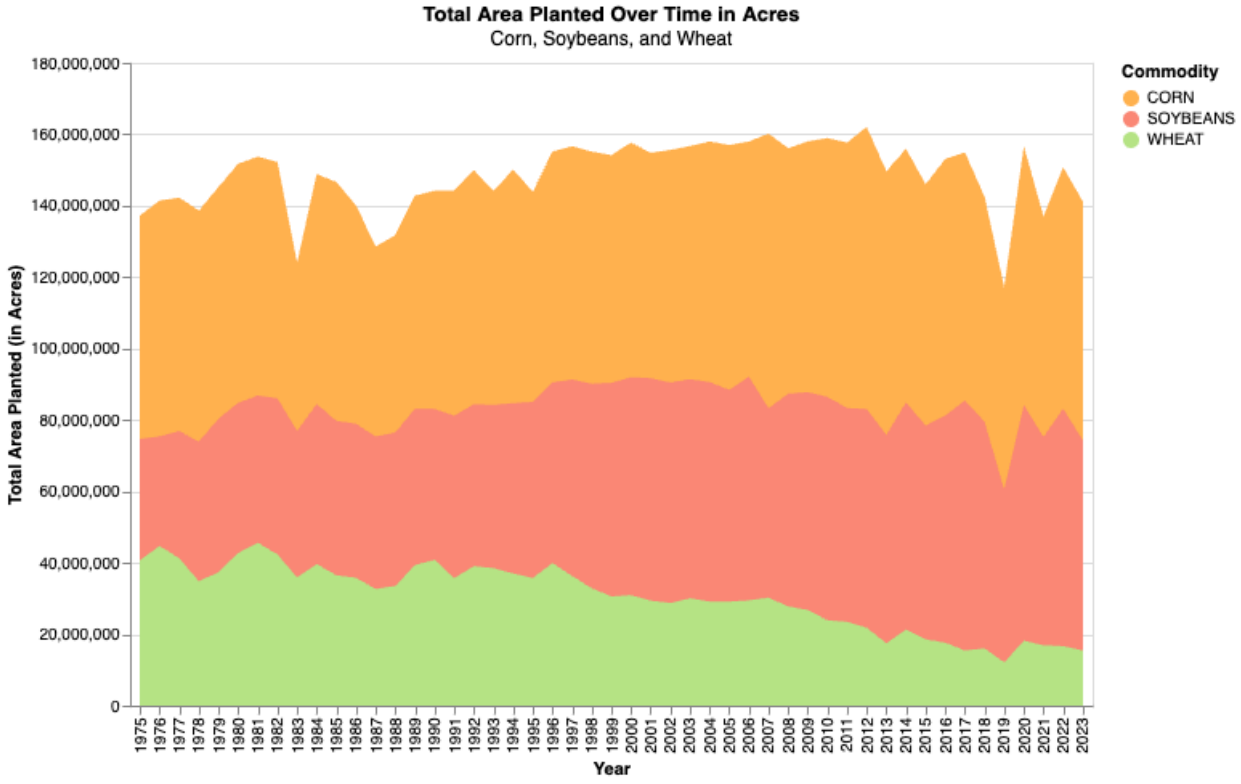
Production is simple the measure of how much of a crop was grown. Field crop production is measured in bushels. Below we have charted annual production by crop type across the period.



Total crop production in Midwest has grown rapidly over the past 50 years. Corn makes up the not only the largest portion of that production, but also accounts for the massive growth in agricultural harvests over the period. Soybean cultivation has increased substantially as well, and it has overtaken wheat is the second most produced crop and has experienced rapid growth as well. Wheat production, on the other hand, has fallen across the period.

Area Planted (in Acres)

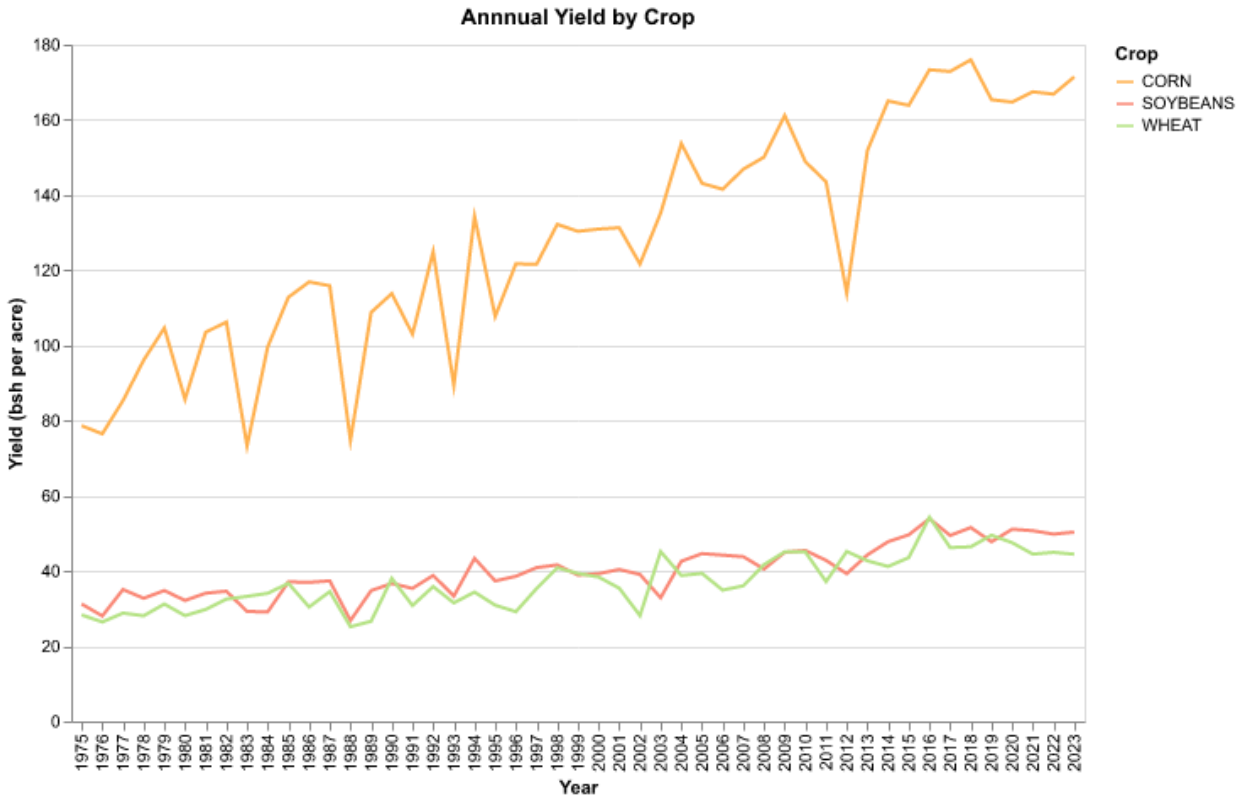
Area planted is simply the amount of land (in acres) that a crop was planted on. Area planted helps us understand how much land was committed to farming a particular crop.



We can see that while the total acreage used to produce these three crops has remained level across the past 50 years, the composition of how it is used has not. The land devoted to corn cultivation is constant, but soybeans seem to have replaced wheat. This drop in the amount of land used to grow wheat helps us understand the drop in total wheat production.

Yield (in Bushels per Acre)

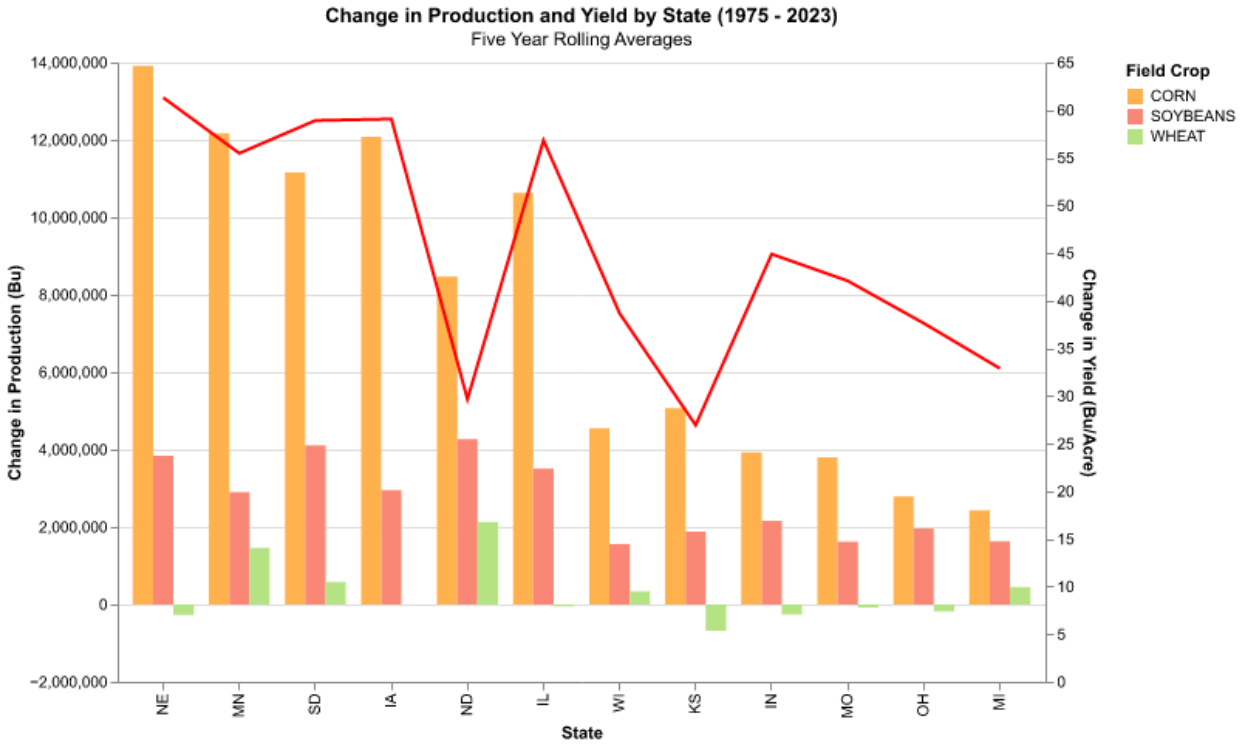
Yield is the total amount of crop produced divided by the area planted to produce that amount (bsh / acre). Yield is a measure of productivity as it helps use quantify what quantity of crops a farmer was able to cultivate from an acre.



Our graph of yield shows us that corn is highly productive and has become even more productive. We can see the yields have increased for soybeans and wheat as well, but at a much slower rate than corn.

By looking at the region, we can see corn production and productivity (yield) has skyrocketed across the recent past. Wheat and soybeans are clearly still very significant crops but haven't experienced the same scale of yield growth. But are these trends uniform across the region? The Midwest is a large region with large differences in climate, urbanization, governance so let's zoom into a state level view.

Variation by State



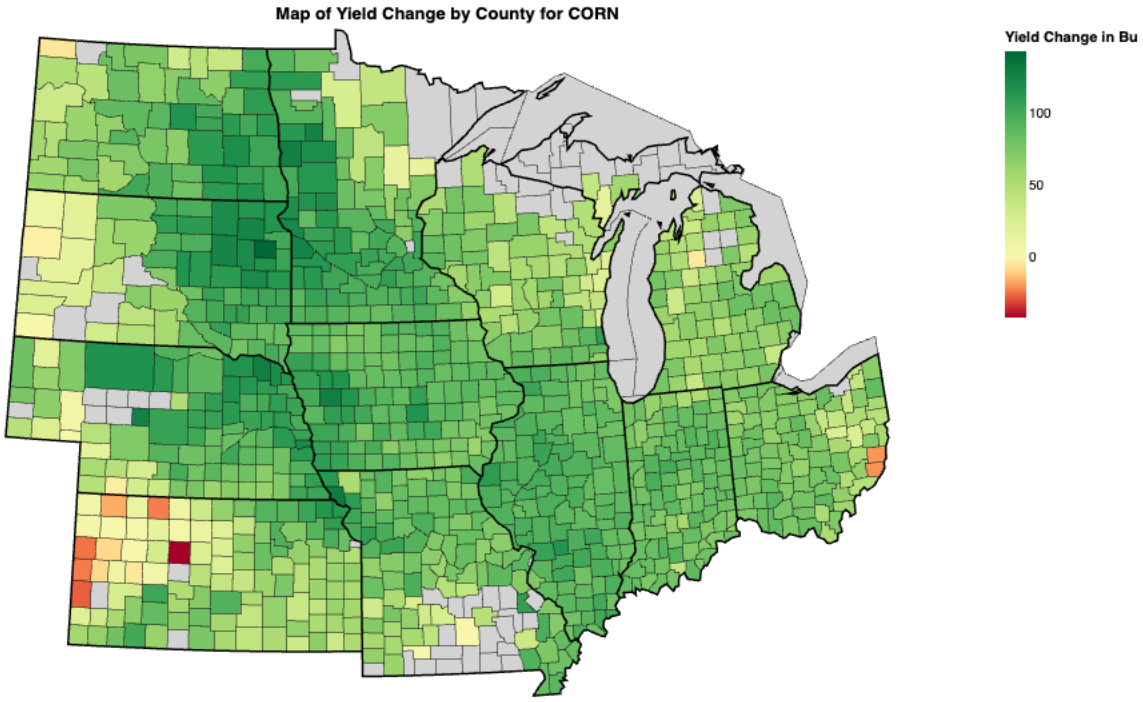
The mixed bar-line chart highlights how production (by crop type) and aggregate yield (across all crops) have changed across our period of analysis. Overall production has grown across all states, with wheat being the only crop experiencing declines in some states. We can also see that the states in the northwestern portion of the Midwest have experienced the largest increases both in production and productivity.[1] The fact that yield has also increased indicates that the production boom is not simply attributable to more land being used to cultivate corn and soybeans in this area. This observation leads us to our next question to investigate: what has caused this boom in productivity in the northwestern Midwest over the past 50 years?

One thing we do know from our regional analysis is that corn is the key driver of both aggregate production growth and productivity growth. So, as we move to the next portion of our investigation, we are going to focus on changes in corn.

[1] North Dakota (ND) is increase in yield over the period is lower than the other northwestern states due to increases in soybean and wheat production. Those crops have lower yields.

The Corny County Picture

To better understand the disparities among states in yield growth, we will need to zoom in a bit further to the county level. Let's look at the change corn yields at the county level.



The choropleth provides a more localized view on where exactly yields have grown the most across the region and within each state. As expected, we see the counties in upper northwest region experiencing the largest increases in productivity. We can see the eastern portions of ND, SK, NE as well the western parts of IA and MN have counties with the greatest productivity gains. Productivity across the entire region has increased, with only counties in the far west experiencing flat or declining yields across the period. Corn yields in the eastern counties have increased, just not to the extent they have in the upper Midwest.

So now that we have a more specific understanding of where exactly corn yields have boomed over the past 50 years, we can start to explore what could be driving this growth.

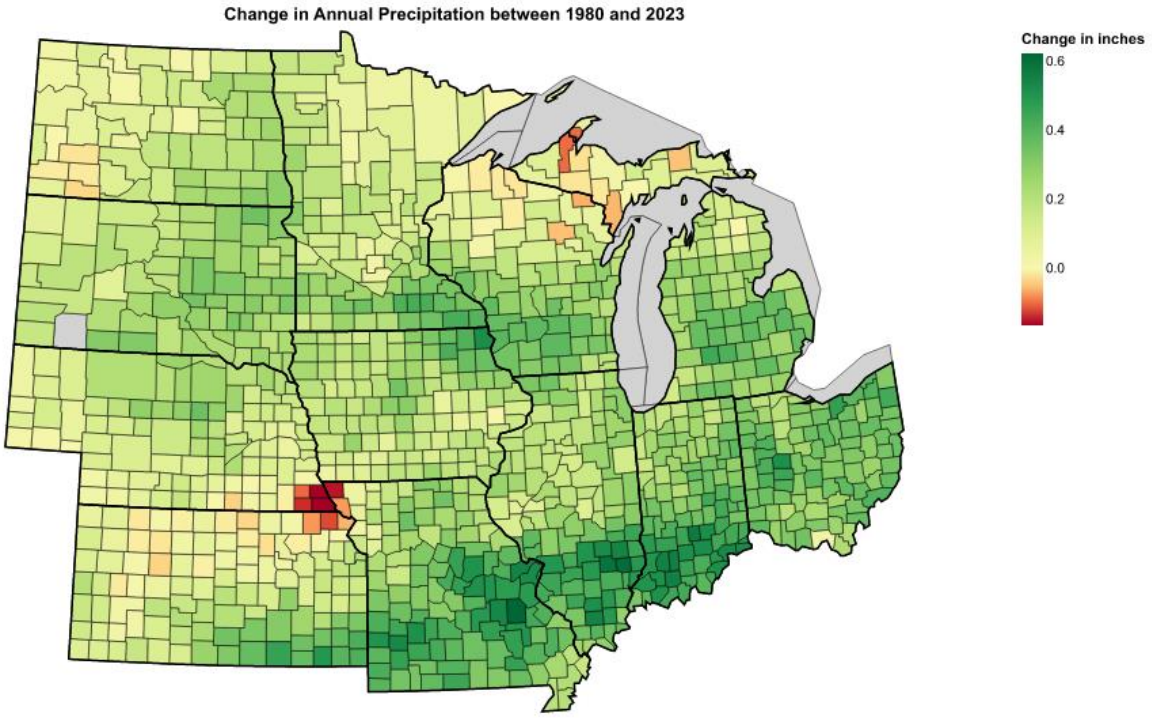
Localized Climate Change

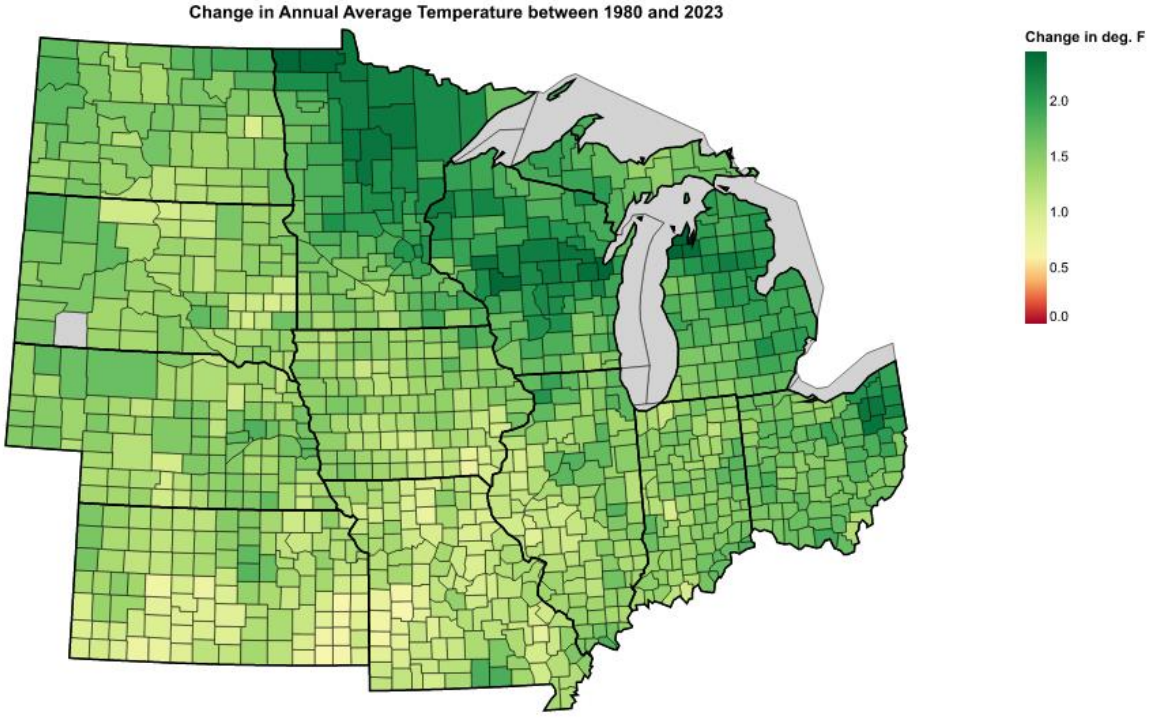
Before we dive into how the region climate has changed in the past 50 years, it's worth taking a moment to consider the complexity of crop productivity. In short, many factors impact how productive a given farm is. Factors such as seed varieties, farming techniques, irrigation systems development and soil nutrient levels are all very important, non-climate factors that influence how much corn can be pullout of acre of land. Advancements in all these domains have likely contributed to the general increase in productivity across the entire region. But for the sake of our simplified analysis, let's just assume that enhancements in these fields have been uniform across the region. This way we can think conceptualize differences in productivity gains across counties through a climate lens.

Though many factors determine corn yields, climate features are widely recognized as some of the most important. Temperature and precipitation during the growing season are critical to successful cultivation. For our analysis, we will use average annual temperature and average annual precipitation. Using average annual temperature and precipitation is far from a perfect metric to evaluate climate impact on corn production. The reality is that the climate during the growing season is most significant but due to data limitations we will need to use annual averages in place of the most relevant data. For our purposes, these data are correlated with the most important climate data.

To measure climate, we will use a 30-year rolling average. Moving forward, when I note that we are comparing the climate of a county in 1980 to the climate in 2023, I mean we are comparing the average climate feature value from 1950-1980 with the average from 1993-2023.

With those notes out of the way, let's begin our analysis of the potential impact of climate change in the region by examining the change in the average annual temperature and average annual precipitation across the past 50 years.





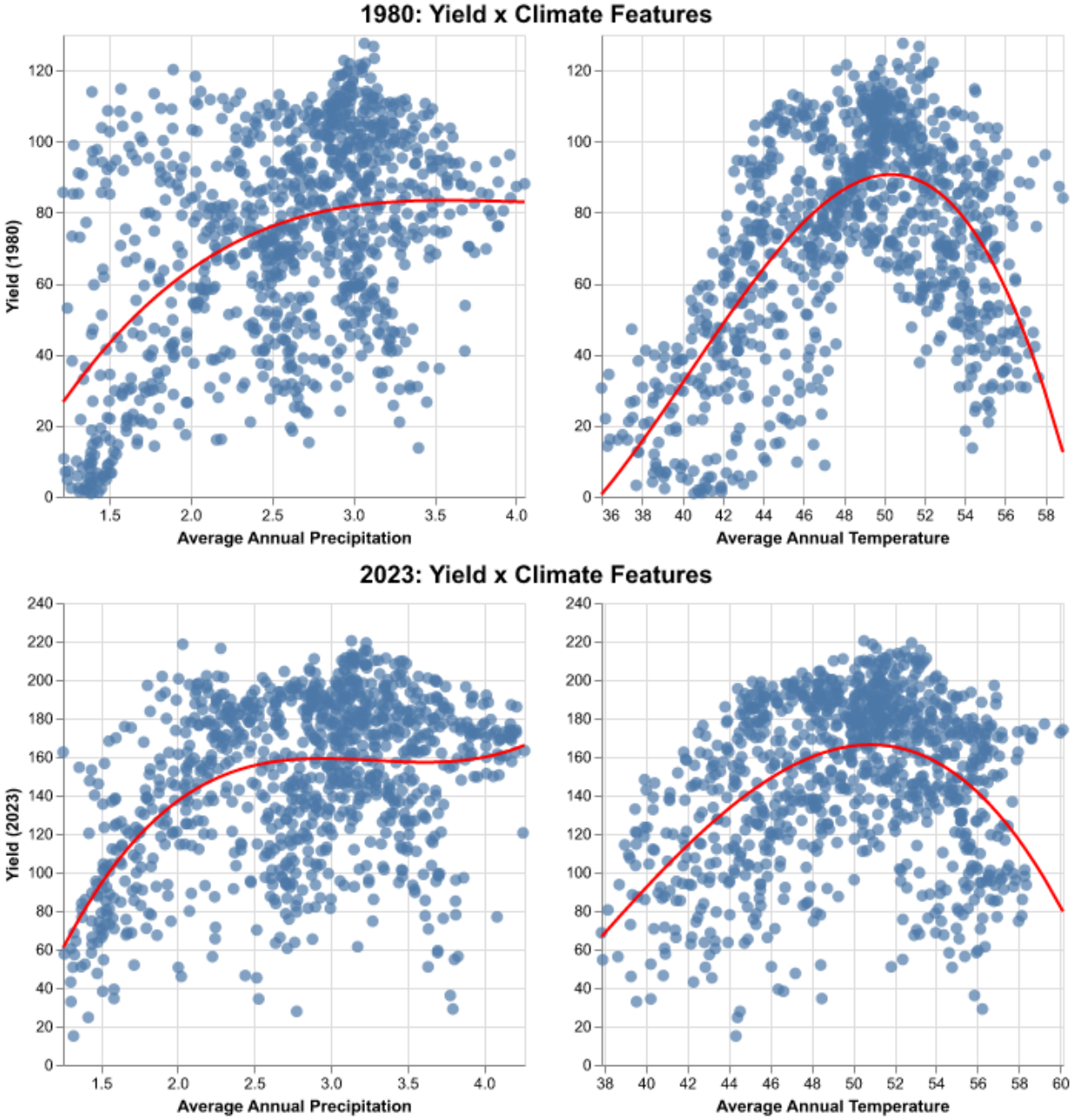
In general, the entire region has become wetter and hotter. The precipitation change map shows us that the south and east have experienced the largest increases in average annual rain fall. The temperature change map shows us that the northeast has experienced the largest increases in temperature.

These maps do not provide any damning evidence for why the northwestern portion of the Midwest has experienced such dramatic growth in corn productivity. It doesn't seem that the subregion has experienced some unique change in its climate relative to the rest of the Midwest.

But this makes sense. The raw change in climate features likely isn't the best metric for our situation. All crops tend to grow best in an optimal climate that is unique to each kind of crop. In the case of corn, the optimal temperature average temperatures during the growing season are between 68- and 73-degrees Fahrenheit. Optimal precipitation varies across the growing season given the state of development the crop is currently in. Therefore, we wouldn't expect the same absolute change in temperature or precipitation to have the same impact of southern Missouri and northern Minnesota.

Approximating the Climate Optimum

Since we unfortunately don't have access to average climate data within the growing season itself, let's try to figure out what the climate optimum looks like in terms of average annual temperature and precipitation.

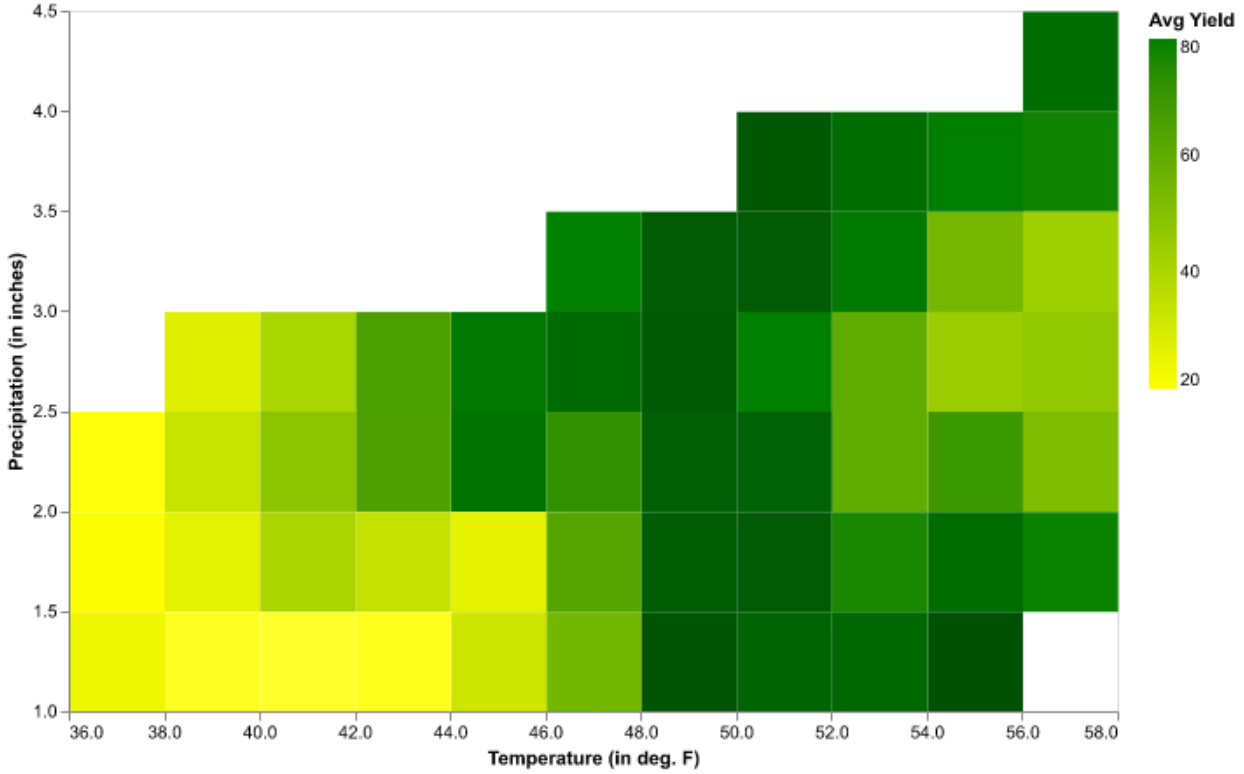


Above we've scattered all the counties in the Midwest based on their corn yield by their average temperature and average precipitation and fit a polynomial regression line to the data to pick up any correlation. While the relationship between annual average precipitation and yield seems clear enough to draw any conclusions, temperature seems to highlight a convex relationship between average annual temperature and yield. We can see a general trend that as average annual

temperatures rise, productivity rises until around 48–52-degree range when it begins to dip back downwards. These scatter plots would seem to indicate that those counties with average temperatures between 48-52 degrees seems to have the highest yields on average. These scatter plots provide some evidence for using the 48-52 range as an optimal let's use a heatmap to look at this same data through a different lens.

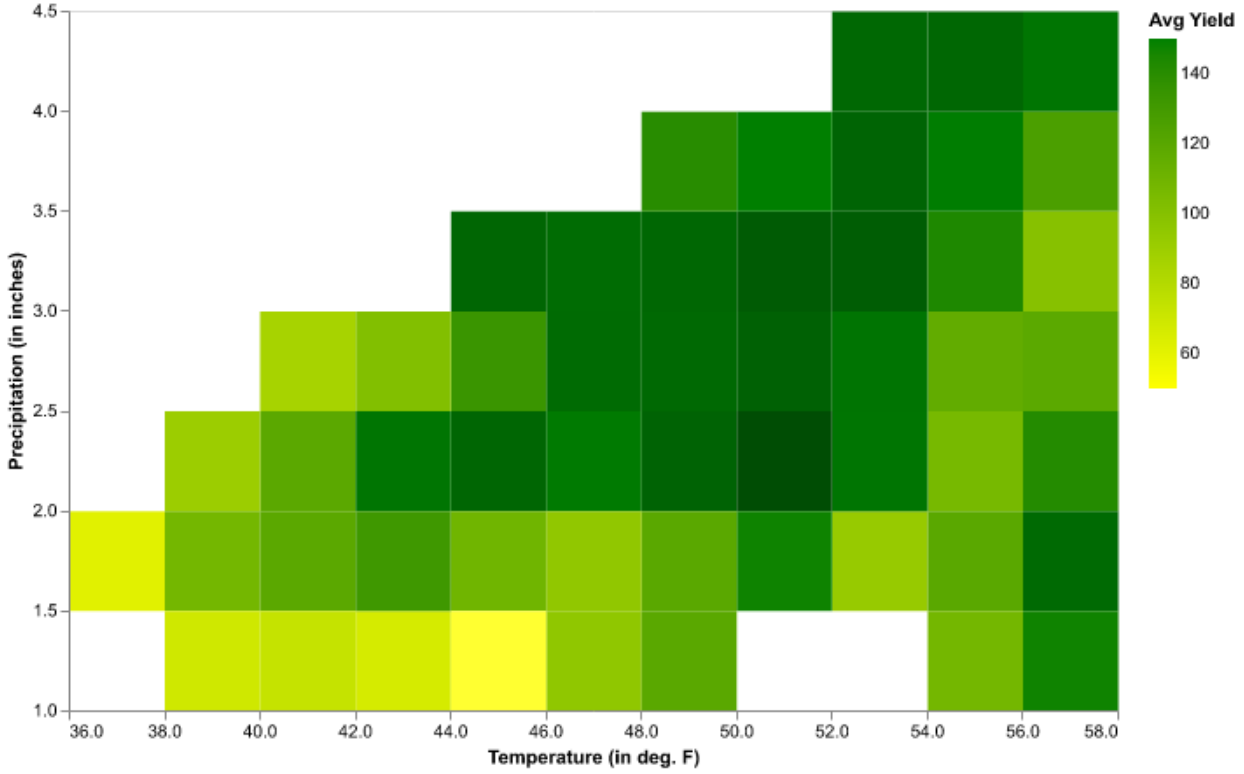
Heat Map of Average Corn Yield (1975-1980)

Corn Yield (bsh/acre) for Counties Grouped by Climate Averages in 1980



Heat Map of Average Corn Yield (2018-2023)

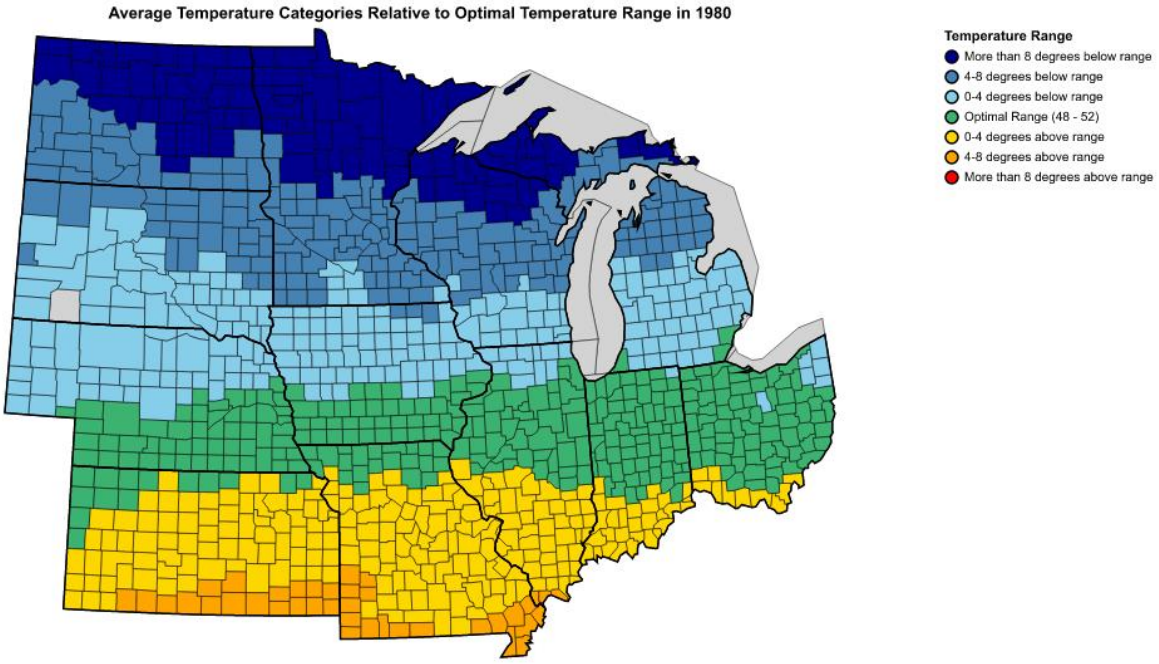
Corn Yield (bsh/acre) for Counties Grouped by Climate Averages in 2023

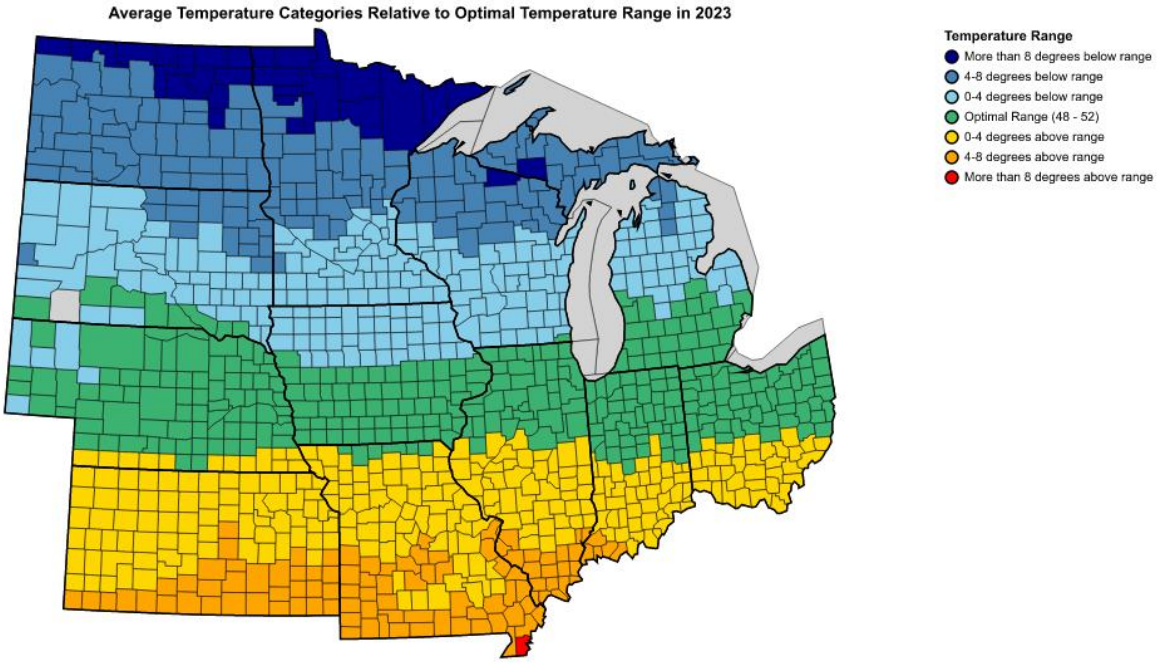


The two heatmaps provide further evidence for using a 48–52-degree optimal range classification. In both time periods, we can see counties with average temps around the 48-52 range had the highest yields based on the climate averages across both periods. Again, the precipitation level seems to have a less clear relationship. There is some variation between the two maps however, it seems that lower precipitation counties are less productivity now that in 2023 than in 1980. And counties with average temperatures below 48 but higher precipitation are increasingly productive. Nevertheless, since we are more interested in using our conclusions about the optimal temperature range to benchmark how average temperatures have changed across the region, we don't need to identify the perfect optimal climate.

Given the stronger relationship we can observe between temperature and yield, let's use average annual temperature to categorize our counties. To better understand how temperature changes in the Midwest have impacted crop yields, we are going to categorize counties based on their average temperature's relationship to the optimal production temperature range of 48-52 degrees. The two maps below show how counties temperatures have shifted relative to the optimal range between 1980 and 2023.

Change relative to optimal temperature





These maps show us that optimal temperature for corn production has shifted north over the past 50 years. The counties in the upper northwest of the region are now closer to that optimal temperature than they were 50 years ago. On the other hand, we can see that more southern counties in Ohio, Indiana, Illinois, Missouri, and Kansas have now have fewer counties close to

that optimum. In conclusion, we can see that the general increase in temperatures across the entire region has moved the northwest Midwest from an area that was too cold to produce corn with high levels of productive to a place that is warm enough.