To Plant or Not to Plant? A Soil Temperature Climatology for the Northern and Central Plains

Olivia G. Campbell[A], Natalie A. Umphlett[A], and Crystal J. Stiles[B]

Affiliation:

A. University of Nebraska-Lincoln.

B. NOAA/National Integrated Drought Information System (NIDIS), Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado Boulder.

Corresponding Author:
Olivia G. Campbell
University of Nebraska-Lincoln
Lincoln, NE 68588 USA
ocampbell2@unl.edu

ABSTRACT

Sufficient soil temperatures at the time of planting are essential for a well-established stand in both large-scale agriculture and recreational home gardening. Planting too early in the season increases the risk for frost damage and slow seedling growth while planting too late risks not reaching the required growing degree days (GDD) for plant maturity. In this study, a climatology of the date in which soils reach critical temperature thresholds for crops was developed for the Northern and Central Plains. At least 15 years of soil temperature data from 155 automated stations from six different networks were utilized in this study. Results showed that Minnesota consistently reached each soil temperature threshold last, while south-central Colorado reached each threshold first, with differences in air temperature and soil moisture likely playing a role. These results were incorporated into an online tool that both professional and recreational agriculturists can use to determine when soil temperatures are best for planting. It will also help put soil temperatures into context based on a climatological average.

1. Introduction

Soil temperature plays a major role in the efficiency of plant biological processes that help lead to a well-established stand in both large-scale agriculture, small-scale commercial horticulture, and casual home gardening. Despite differing climate zones and year-to-year variability, crop and agronomic seeds still have soil temperature requirements that must be met in order to germinate, develop, and establish properly. Failure to do so increases the risk for a poor stand and subsequent yield loss, even on scales as small as a backyard garden. This is because temperature controls the effectiveness of many processes in the soil that affect plant growth including water uptake, nutrient uptake, and root growth (Onwuka and Mang, 2018).

Lower soil temperatures can decrease plant water uptake due to increased water viscosity and decreased absorption rates (Onwuka and Mang, 2018; Zhu et al., 2021). Decreased water uptake subsequently reduces the rate of photosynthesis and stomatal conductance. Furthermore, dehydration can occur when soil temperatures are cool but atmospheric temperatures are warmer, a common occurrence in the spring, because root water uptake cannot meet the demands of canopy transpiration (Zhu et al., 2021). Absorption rates of nutrients also depend on temperature as there can be large changes in nutrient absorption and overall plant growth in relatively small soil temperature increases (Gavito et al., 2001). These changes relate to the metabolic activities of microorganisms in the soil. Because many plants rely on these microorganisms to convert nutrients into useable forms, higher soil temperatures are essential for stimulating metabolic activities and ensuring nutrient availability. Concurrently, higher water viscosity, as a result of lower soil temperatures, reduces plant nutrient uptake (Lahti et al., 2004).

TABLE 1. Number of stations used per station network and website link to each network.

Station Network	# of Stations Used	Website Link
Colorado Agricultural Meteorological Network (CoAgMet)	20	http://www.coagmet.colostate.edu/
Kansas Mesonet	10	http://mesonet.k-state.edu/
Nebraska Mesonet	42	https://mesonet.unl.edu/
North Dakota Agricultural Weather Network (NDAWN)	65	https://ndawn.ndsu.nodak.edu/
Soil Climate Analysis Network (SCAN)	15	https://www.wcc.nrcs.usda.gov/scan/
United States Climate Reference Network (USCRN)	3	https://www.atdd.noaa.gov/u-s-crn-groups-map/

The uptake of water and nutrients are major determining factors when it comes to plant growth overall especially early in the growing season (Kaspar and Bland, 1992). Adequate soil temperatures increase root growth and help the development of lateral roots. Root growth responds to accumulated growing degree-days in a similar fashion to above-ground growth (Kaspar and Bland, 1992; Clarke et al., 2015); therefore, low soil temperatures hinder root growth due to low metabolic rate within roots and both water and nutrient uptake (Onwuka and Mang, 2018). However, this relationship goes both ways because root length also determines nutrient uptake of chemicals like phosphorus (Kaspar and Bland, 1992; Gavito et al., 2001).

Water uptake, nutrient uptake, and root growth become limited below 10°C, which is a common soil temperature at the time of planting in temperate regions (Gavito et al., 2001; Prasad et al., 2006). In the United States (U.S.), corn and wheat development are delayed during cool springs with cooler soil temperatures, while warm spring-season soil temperatures contribute to increased corn and wheat yield through root development and subsequent leaf development (Hu and Feng, 2003). Additionally, Hu and Feng

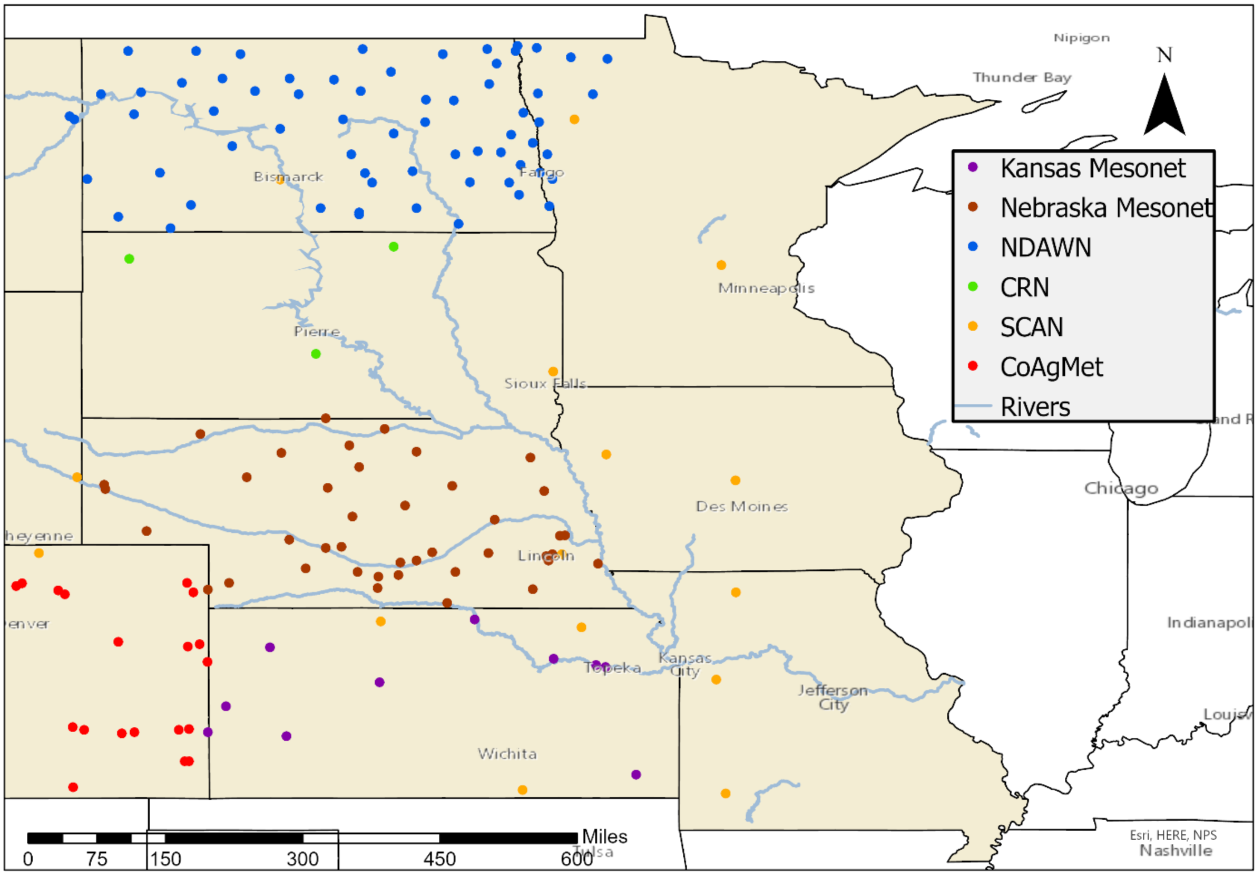

FIGURE 1: Map of the northern and central Plains. Dots represent station locations, and colors represent the different station networks.

TABLE 2. The recommended minimum temperatures needed for seed germination of select agronomic and horticultural crops (Pathak et al., 2012).

Agronomic Crops	Minimum Soil Temperature at Planting (°F)	Horticultural Crops	Minimum Soil Temperature at Planting (°F)
Spring Wheat	37	Spinach	38
Spring Barley	40	Radish	40
Rye	41	Lettuce	41
Oats	43	Onion	41
Alfalfa	45	Pea	42
Spring canola	50	Potato	45
Sugarbeet	50	Cabbage	45
Field corn	55	Carrot	46
Soybean	59	Sweet Corn	55
Sunflower	60	Pepper	57
Millet	60	Snap Beans	57
Sorghum	65	Tomato	57
Dry Bean	70	Cucumber	58
		Pumpkin	60

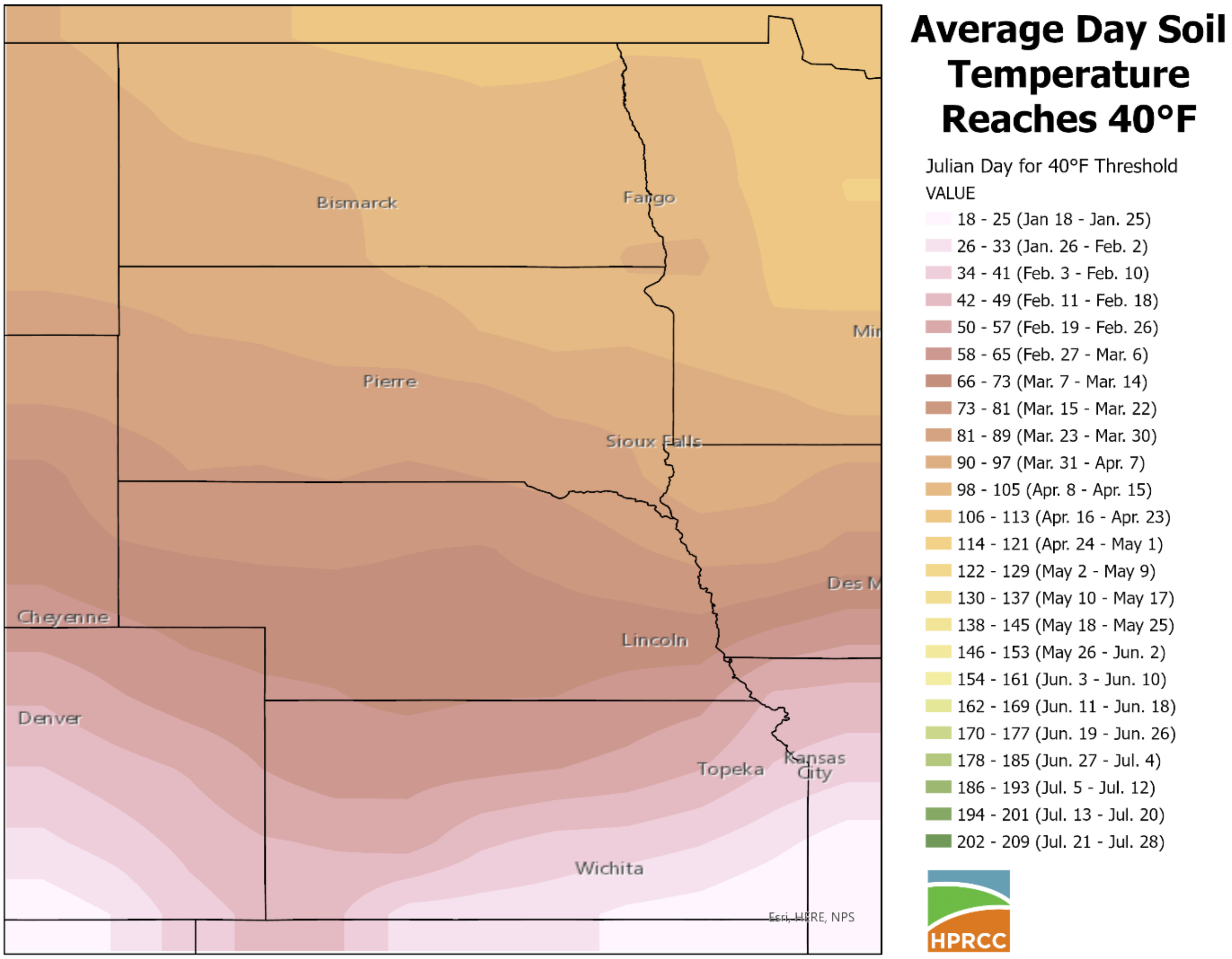

FIGURE 2: Map showing the average Julian (calendar) day soil temperature reaches 40°F.

(2003) found that warmer soil temperatures earlier in the growing season allows for earlier planting and opens the door to using high-yield varieties that take longer to mature. However, year-to-year variability can make it difficult to plant in optimal conditions, especially in the central U.S. where temperature fluctuations can be large, particularly in the spring. This variability also makes it difficult for farmers to select appropriate seed varieties and crop rotations ahead of the growing season.

Although soil temperatures play a large role in agriculture, relatively few studies have approached this topic from a climatological point of view. For instance, Pathak et al. (2012) looked at the average date that soil temperatures reach certain thresholds for crop and agronomic seed germination in Nebraska. Furthermore, Hu and Feng (2003) aimed to create a soil temperature climatology at various depths for the contiguous U.S. Additionally, soil temperature climatology information has been a recurring request at the High Plains Regional Climate Center (HPRCC), but due to a lack of available studies, a regional perspective has not been available. Therefore, this study sought to expand on previous work and answer the question, what is the average date that soil temperatures first reach critical thresholds for seed germination across the northern and central Plains? Results were incorporated into a tool that agriculturalists can use to make informed planting decisions based on climatological soil temperature data.

2. Methodology

Soil temperature data at the 10 cm (or 4 inches) depth at automated stations in the northern and central Plains were used in this study. To get as widespread and as uniform a coverage as possible, 155 stations from 6 networks were used: Colorado Agricultural Meteorological Network (CoAgMET), Kansas Mesonet, Nebraska Mesonet, North Dakota Agricultural Weather Network (NDAWN), Soil Climate Analysis Network (SCAN), and United States Climate Reference Network (USCRN) (Table 1). These stations span Colorado (CO), Iowa (IA), Kansas (KS), Minnesota (MN), Missouri (MO), Montana (MT), Nebraska (NE), North Dakota (ND), South Dakota (SD), and Wyoming (WY). Figure 1 shows the extent of the study region. Iowa, Minnesota, Nebraska, and Kansas rank in the

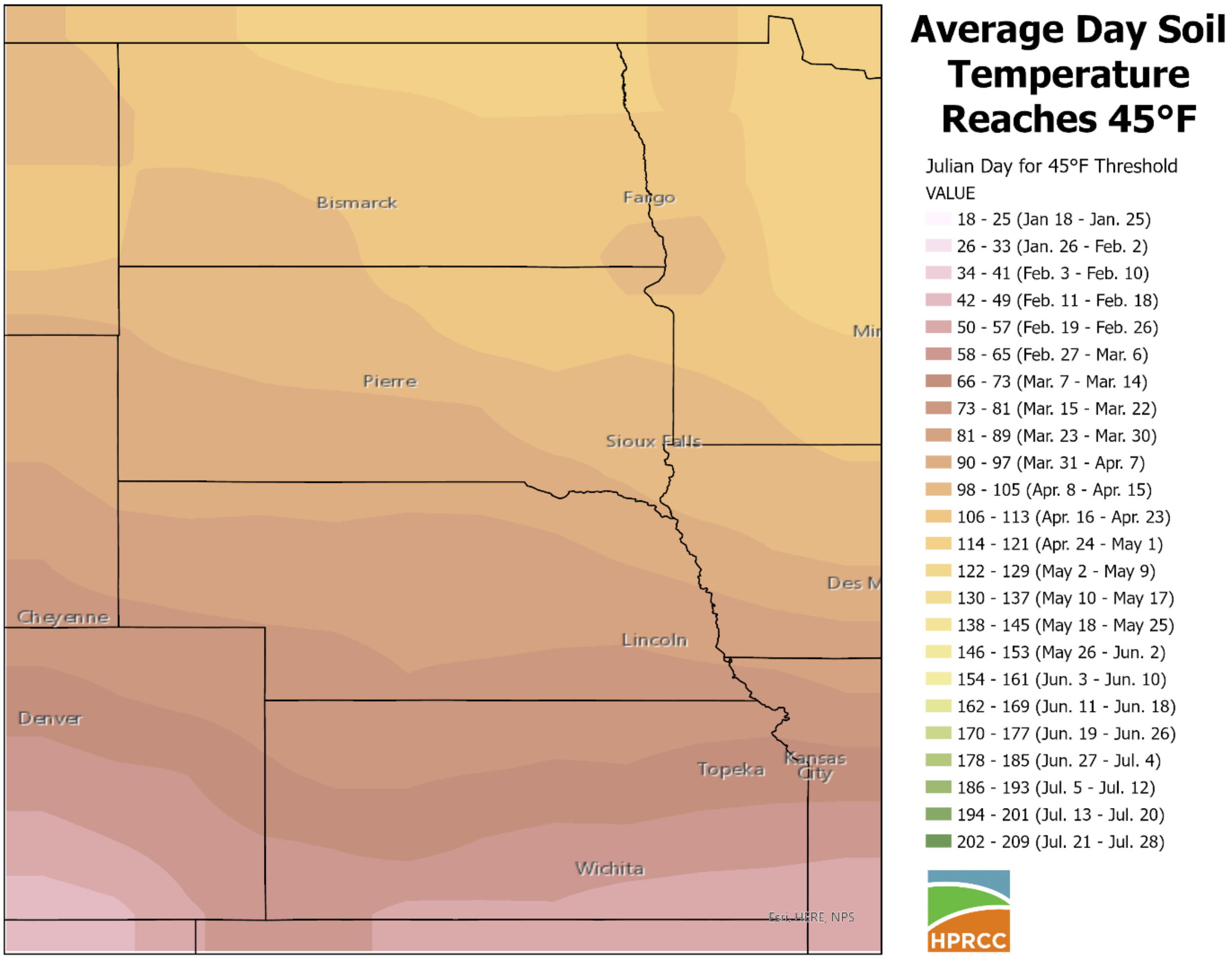

Figure 3: Map showing the average Julian (calendar) day soil temperature reaches 45°F.

top 10 most agriculturally productive states in the U.S. (in terms of both crop and livestock output) at 2, 5, 6, and 7, respectively. Missouri ranks 12, South Dakota ranks 17, Colorado ranks 22, and North Dakota ranks 23 (Wang et al., 2020). The extent of the study area was cut off at the Rocky Mountains due to low agricultural productivity (Montana ranks 31 in total farm output and Wyoming ranks 38) and sparse station availability. Since this project focuses mainly on the northern and central Plains, the sparce station locations in Minnesota, Iowa, and Missouri were seen as a way to help limit edge effects from interpolation along the main area of study.

Our study used stations with at least fifteen years of soil data, from 2006 to 2020. We chose fifteen years because this length of time provided a good balance between station spatial coverage and temporal coverage. Moreover, stations could have a longer period of record (record start dates before 2006), but the record had to extend through 2020 to maintain data uniformity. One exception to this rule was regarding the stations in South Dakota. These stations only had nine to ten years of soil temperature data ending in 2020, but we favored spatial coverage over temporal coverage in this instance. As previously mentioned, each station network records soil temperature at 10 cm (4 inches), with the exception of CoAgMET, which records soil temperature at 5 cm (2 inches) and 15 cm (6 inches). Fortunately, we found that averaging the two values gave us an accurate 10 cm estimate (4 inches). Soil probes were found under both bare and covered ground. Although there are nearly 500 automated stations with soil temperature data in the study region, only 155 stations met these requirements and were used in this study (Figure 1).

After determining which stations to use, soil temperature data from each station were assessed for quality assurance purposes. Next, we calculated a five-day running average of the soil temperature data for the entire period of record. Afterward, any missing or erroneous values were removed. Individual years with two months or more of missing data between January and June were removed and not used in the study. Once the data were formatted correctly, they were exported into a comma-separated values (CSV) text file and ran through a Python script. Based on Table 2 and the Pathak et al. (2012) study, many common agricultural crops require minimum soil temperatures at planting between

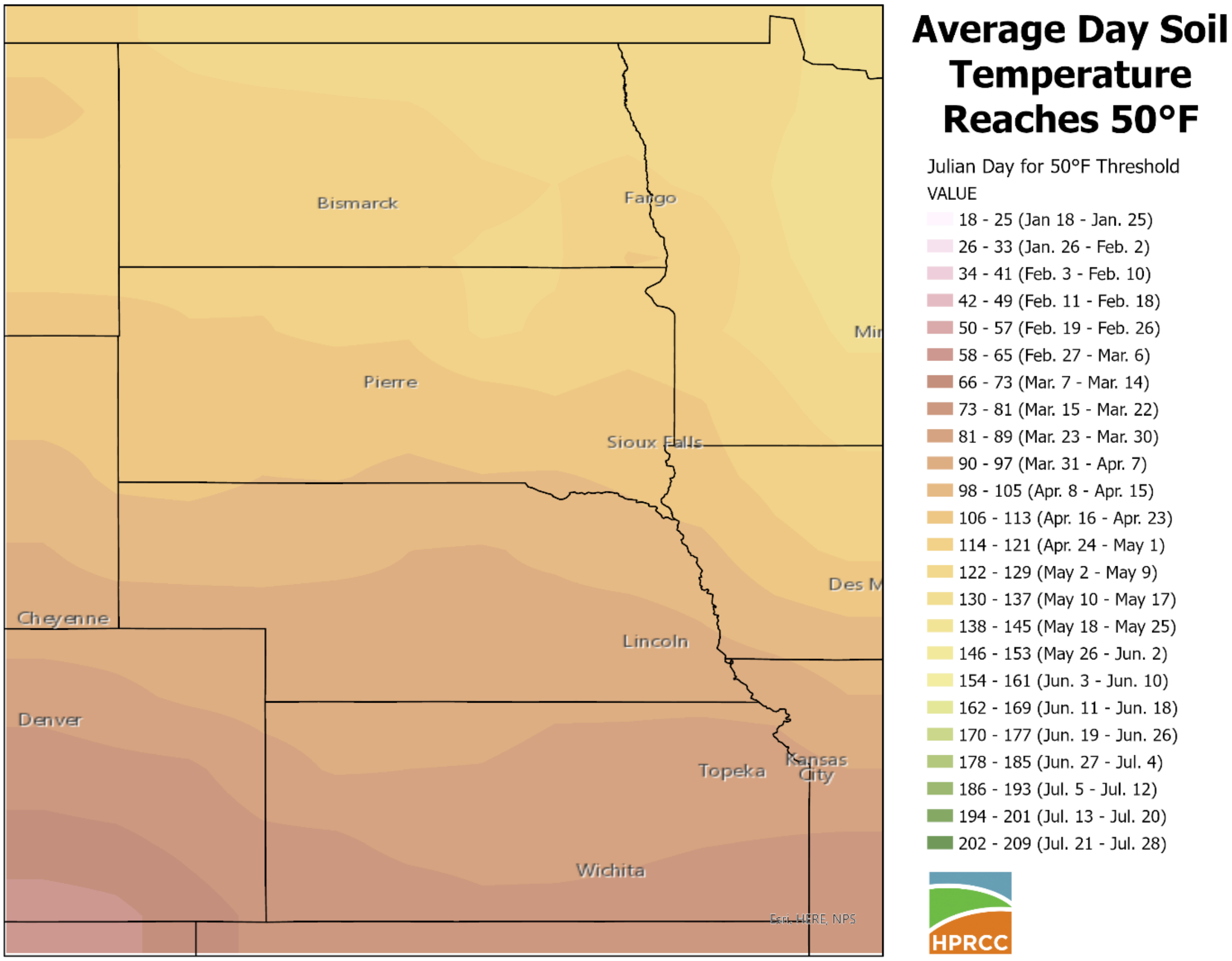

Figure 4: Map showing the average Julian (calendar) day soil temperature reaches 50°F.

40°F and 70°F, so we found the first occurrence of the five-day running average of soil temperature at or above 40°F, 45°F, 50°F, 55°F, 60°F, 65°F, and 70°F. Once it was found, the Julian date was recorded and then averaged over the total number of dates found after going through each year in the dataset. This was done for each threshold. The result was the average Julian date that soil temperatures reached a threshold listed above for a specific station.

Two sets of maps were made from the results of the 155 stations: seven maps showing interpolated values for each temperature threshold and seven dot maps showing graduated colored points at each of the station locations (one map for each temperature threshold listed above). Both sets of maps were made in ArcGIS Pro and the Julian days were grouped into seven-day periods. The seven interpolated maps were made using the Universal Kriging with linear drift technique, which is preferred over inverse distance weighting (Pathak et al., 2012) for soil science and geology because it produces smoother interpolation lines and fewer "bullseyes" in the interpolation (ESRI, 2021). ESRI (2021) also describes it as the best method for detecting directional bias in the data, which in this case takes the form of a latitudinal soil temperature gradient. The seven dot maps were made with a graduated colors symbology to represent the Julian week that each soil threshold was reached for each location. These maps serve as a supplement to the interpolation maps, giving users the option to see the actual values at individual locations.

3. Results & Discussion

Figures 2 – 8 show the average Julian days that soil temperature reaches thresholds deemed necessary for the successful germination and establishment of agricultural and horticultural crops. Looking at the seven figures as a collective group, it is evident that east-central Minnesota consistently records the latest Julian dates any threshold is met. Conversely, south-central Colorado records the earliest Julian days for each threshold when met. Additionally, as the temperature thresholds increase, the northern half of the study area becomes increasingly "irregular." Julian day ranges become less uniform compared to the southern half of the region as one progresses through the growing season. This could be tied to influxes of colder, Canadian

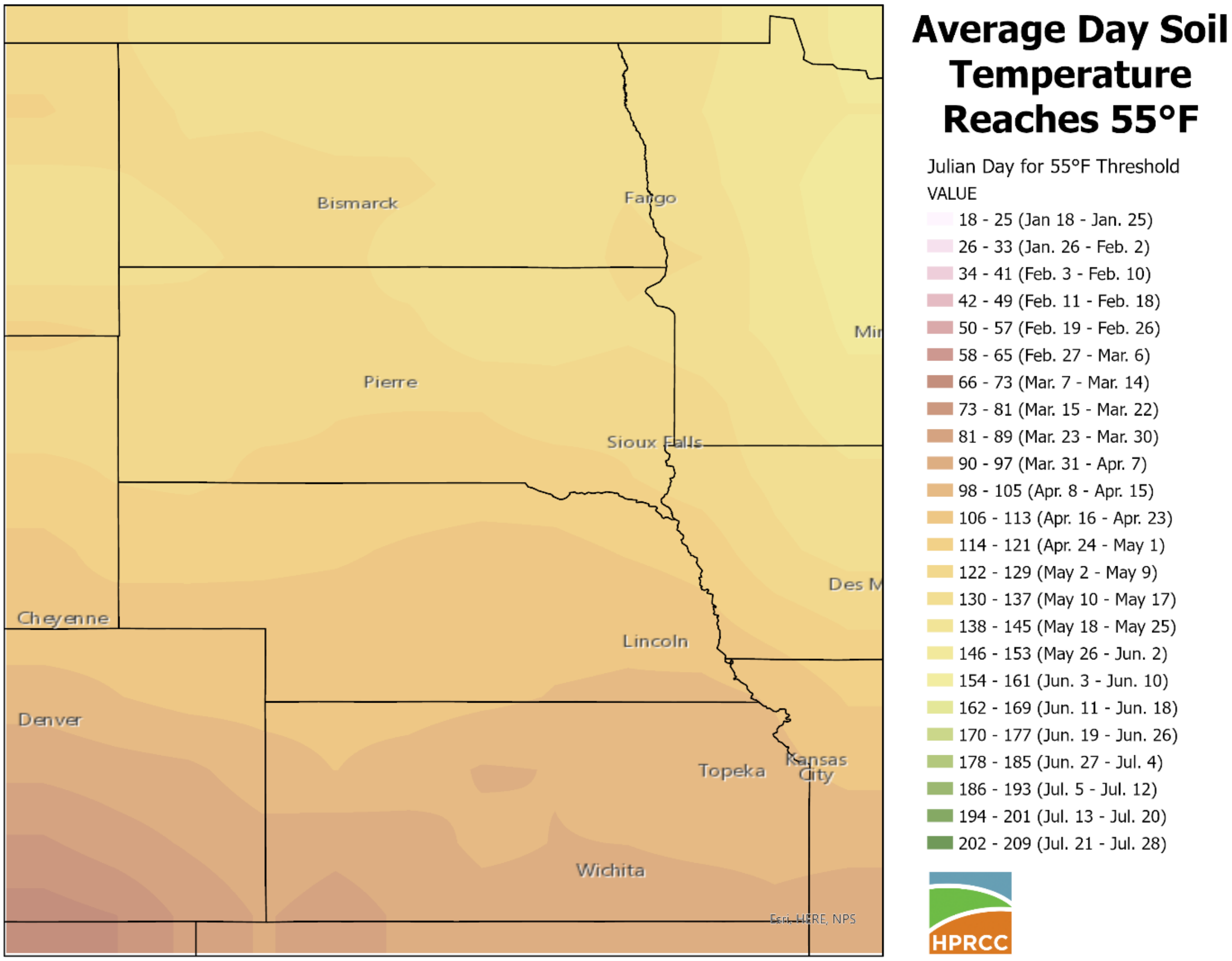

Figure 5: Map showing the average Julian (calendar) day soil temperature reaches 55°F.

air sometimes seen in the northern Plains during the spring months as well as variations in snow cover (Grundstein et al., 2005; Maurer and Bowling, 2014).

Figure 2 displays the interpolated average calendar day the soil temperature reaches 40°F. Julian days range from as early as 18 (January 18) in southeast Kansas, western Missouri, and south-central Colorado to as late as 113 (April 23) in northern and central Minnesota and along the Canadian border in North Dakota. There appears to be a much tighter Julian day gradient in the southernmost part of the study area, but it quickly becomes more spread out into Nebraska and farther northward. This indicates that soils in Missouri, Kansas, and Colorado reach 40°F much more quickly and earlier in the year, but the time it takes to reach 40°F slows down as one moves north toward the Canadian border, shown by larger separations between the range of days. This would make sense, since the landlocked nature of the Northern Plains makes the region vulnerable to cold spells in the spring (U.S. Climate Resilience Toolkit, 2021). The 40°F threshold also has the longest range of Julian days of all the thresholds at 95 days.

Figure 3 shows the average calendar day the soil temperature reaches 45°F. Julian days range from 50 (February 19) in the far southern regions of the study area to 121 (May 1) along the Canadian border and is one of the shortest ranges in Julian days of all the thresholds at 71 days. Day ranges appear more uniform compared to the 40°F soil temperature map (Figure 2), but become more distanced and irregular into Minnesota and North Dakota. This hints at a relatively steady progression of 45°F soil temperatures from south to north across the north-central Plains over about a 71-day period.

Figure 4 displays the average calendar day soils reach the 50°F threshold. Julian days range from 58 (February 27) in far south-central Colorado to 137 (May 17) in eastern Minnesota. What is interesting here is that the range of days begin to lag from Minnesota into Iowa and far northern Missouri compared to the location of the same thresholds in the central and western parts of the study area. For example, Pierre, SD and Des Moines, IA both fall within the 106 – 113 day range, but Des Moines is about 150 miles farther south than Pierre. The authors speculate that the onset of 50°F soil temperatures happens much more quickly along this area of later dates as one moves north compared to the

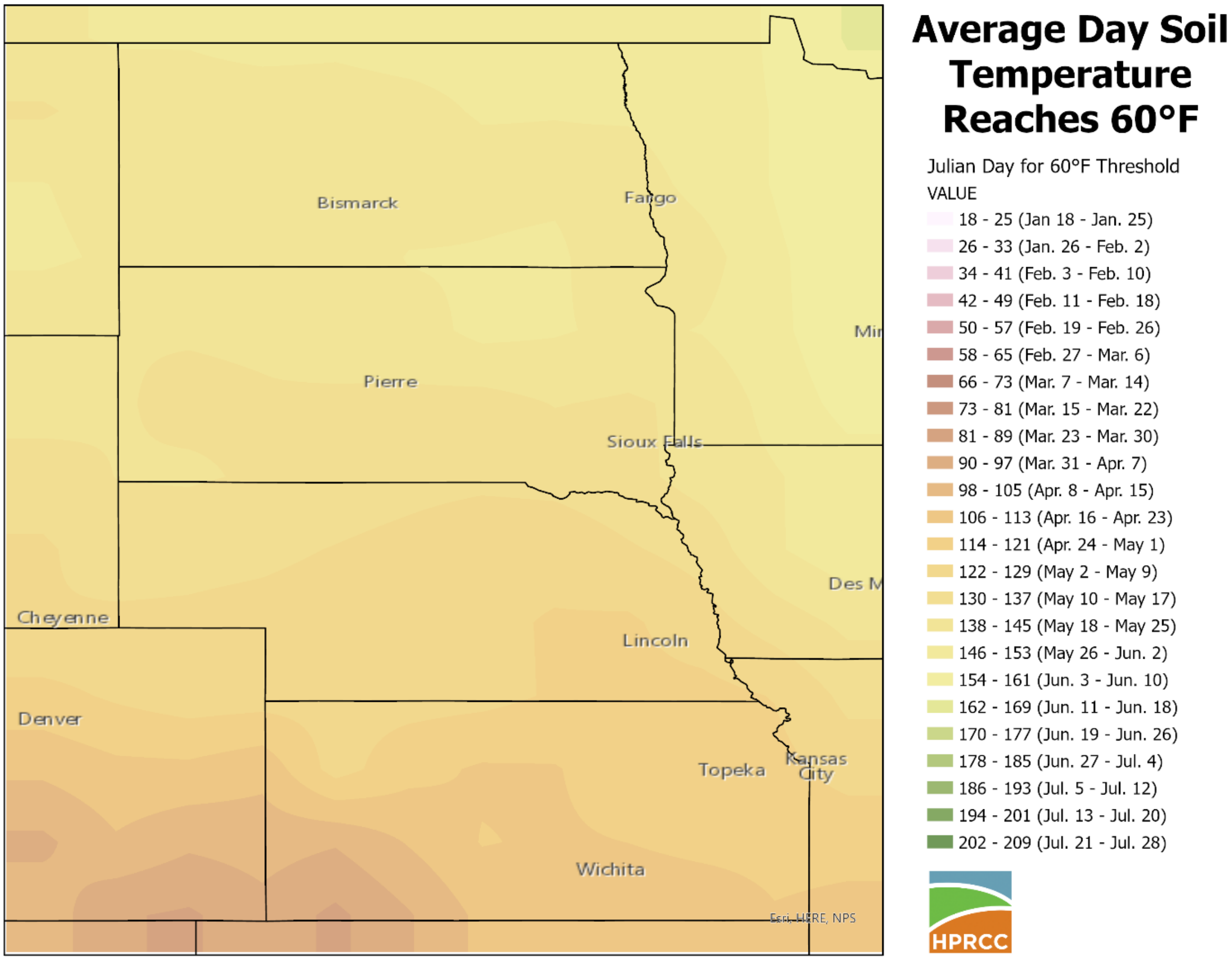

Figure 6: Map showing the average Julian (calendar) day soil temperature reaches 60°F.

rest of the region, but the 50°F threshold occurs much later in the year compared to western locations along the same latitude. However, more data, especially in South Dakota and Iowa, would be needed to verify this assumption.

Figure 5 depicts the average calendar day soil temperature reaches 55°F. Days range from 66 (March 7) in far south-central Colorado to 153 (June 2) in east-central Minnesota. Again, the lagging of ranges along the eastern border of the study area is evident where soil temperatures take longer to reach the 55°F threshold. The 60°F soil temperature map (Figure 6) shows a similar distribution to the 55°F map (Figure 5). Julian dates range from 90 (March 31) in southeastern Colorado to 161 (June 10) in eastern Minnesota. Similar to the 45°F threshold (Figure 3), the 55°F threshold shares the shortest range of Julian days of all the temperature thresholds studied at 71 days.

Figure 7 indicates that the average Julian dates that soil temperature reaches 65°F range between 98 (April 8) and 185 (July 4). Eastern Minnesota continues to record the latest dates the threshold is reached, while far south-central Colorado records the earliest dates the threshold is reached. The day range gradient across Colorado and Kansas is relatively evenly spaced, but into Nebraska and farther north the ranges become more irregular. The lagging of later Julian dates is very evident across Minnesota and Iowa.

Figure 8 shows the average calendar day soil temperature reaches 70°F. Again, soil temperatures reach 70°F first in south-central Colorado at Julian day 114 (April 24) and last in southeastern Minnesota at Julian day 201 (July 20). For over half the study area, soil temperatures do not reach 70°F until at least June 11, or Julian day 162. One explanation for this could be the depth and duration of snowpack. Interestingly, in certain years, some stations in Minnesota and North Dakota failed to record soil temperatures reaching 70°F.

There is a possible explanation that helps describe the change in the interpolation patterns as the threshold temperatures change, especially when examining the lagging effect seen in the 50°F, 55°F, 60°F, 65°F, and 70°F maps (Figures 4 – 8). Looking at the soil moisture regime map in Figure 9 (USDA NRCS, 2021), there is a boundary running from central North Dakota southeast into South Dakota, then due south into Nebraska and Kansas. This boundary separates wetter, more humid climate soils from drier,

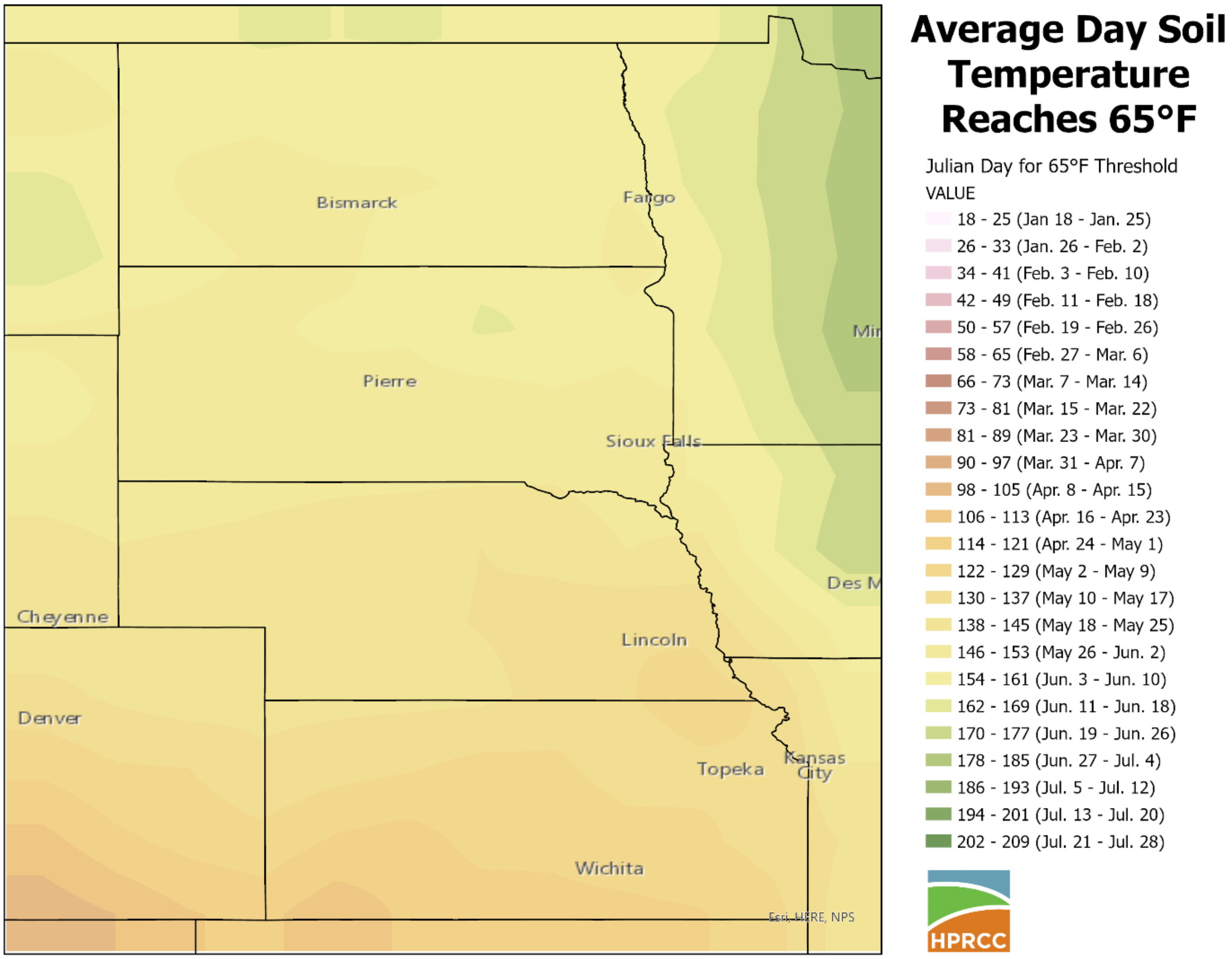

Figure 7: Map showing the average Julian (calendar) day soil temperature reaches 65°F.

semi-arid climate soils. This boundary lies in a similar location to where the lagging effect begins in Figures 4 – 8. This implies that soil moisture may play a role in how quickly soils heat up in the spring, along with other factors such as air temperature and snowpack; wetter soils will take longer to heat up because of the high specific heat of water, but drier soils will heat up more quickly due to the much lower specific heat of soil constituents (Oschner, 2019). Our results further support this idea by showing that northern and central Minnesota continuously record the latest dates any threshold is met, while south-central Colorado continuously records the earliest dates any threshold is met. According to the USDA NRCS (Figure 9), Minnesota also contains the most saturated soil moisture regimes (aquic, udic). In contrast, southern Colorado contains drier, more arid soil moisture regimes (aridic, ustic) (Agri learner, 2018).

4. Soil Temperature Climatology Tool

Due to year-to-year variation in the climate, soil temperature can be just as variable. This tool (https://hprcc.unl.edu/maps.php?map=SoilTemp#) has taken that year-to-year variability and reduced the noise to give a more solid idea of when soil temperatures are reaching important thresholds. Both casual and experienced agriculturalists can use this tool as a reference for approximately when in the year they should plant based on their location. For example, if a home gardener in Lincoln, NE wants to plant cabbage with a minimum soil temperature at planting of about 45°F (Pathak et al., 2012; Table 2), then the best time to plant would be between March 23 and March 30 (Julian days 81 – 89). However, if the same gardener lived in Bismarck, ND, they should not plant until April 16 – April 23 (Julian days 106 – 113), according to Figure 3.

There is one caveat that must also be addressed to keep in mind when using the tool. This study uses the first occurrence a temperature threshold is reached, rather than the last. What this implies is that a soil temperature threshold could be reached, but later drop back below the threshold. This is one advantage to using a range of days as well: it helps to account for possible instances of soil temperatures dropping back below the threshold and rising again. Additionally, this phenomenon is more likely to occur earlier in the season and therefore affect lower thresholds the most (40°F, 45°F,

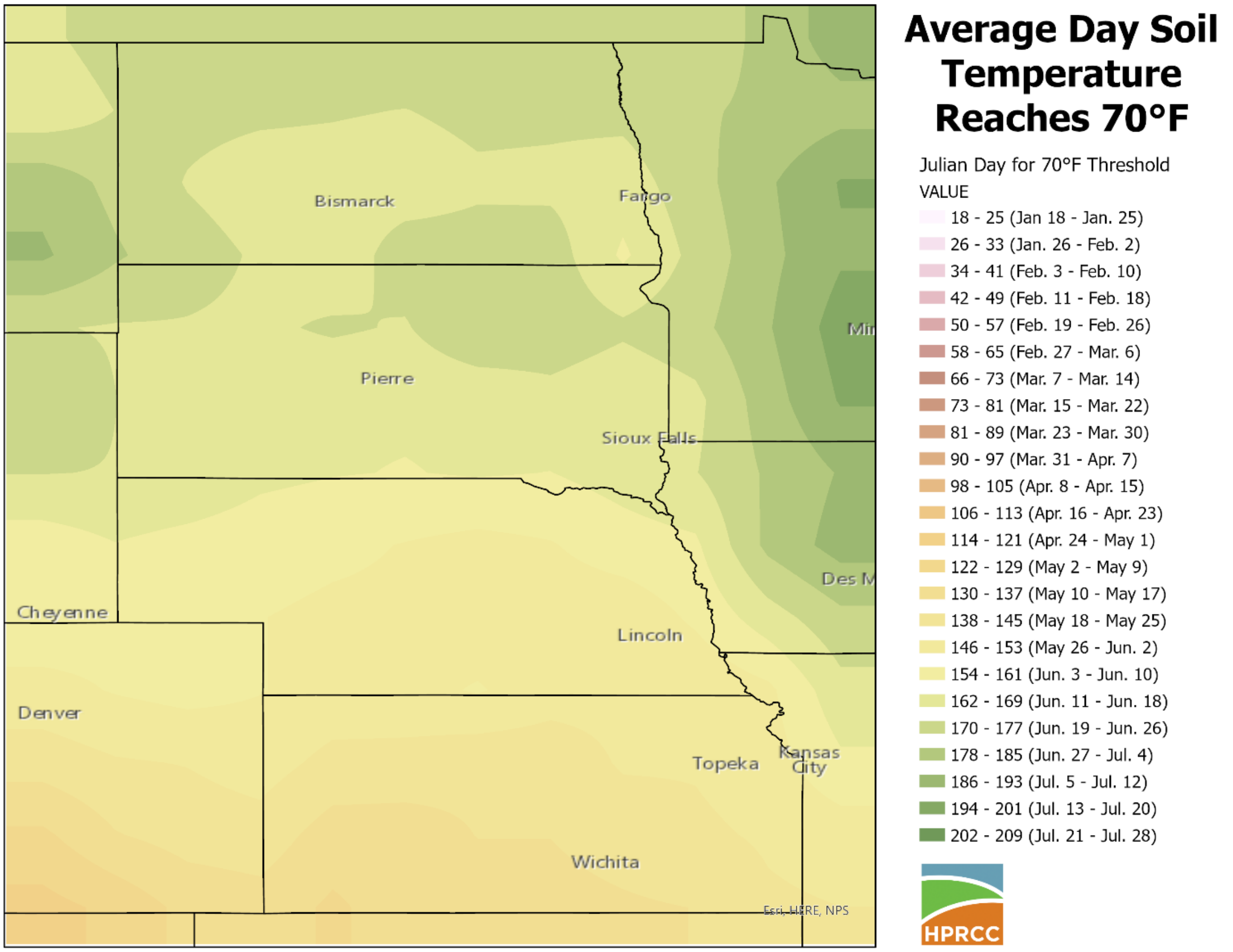

FIGURE 8: Map showing the average Julian (calendar) day soil temperature reaches 70°F.

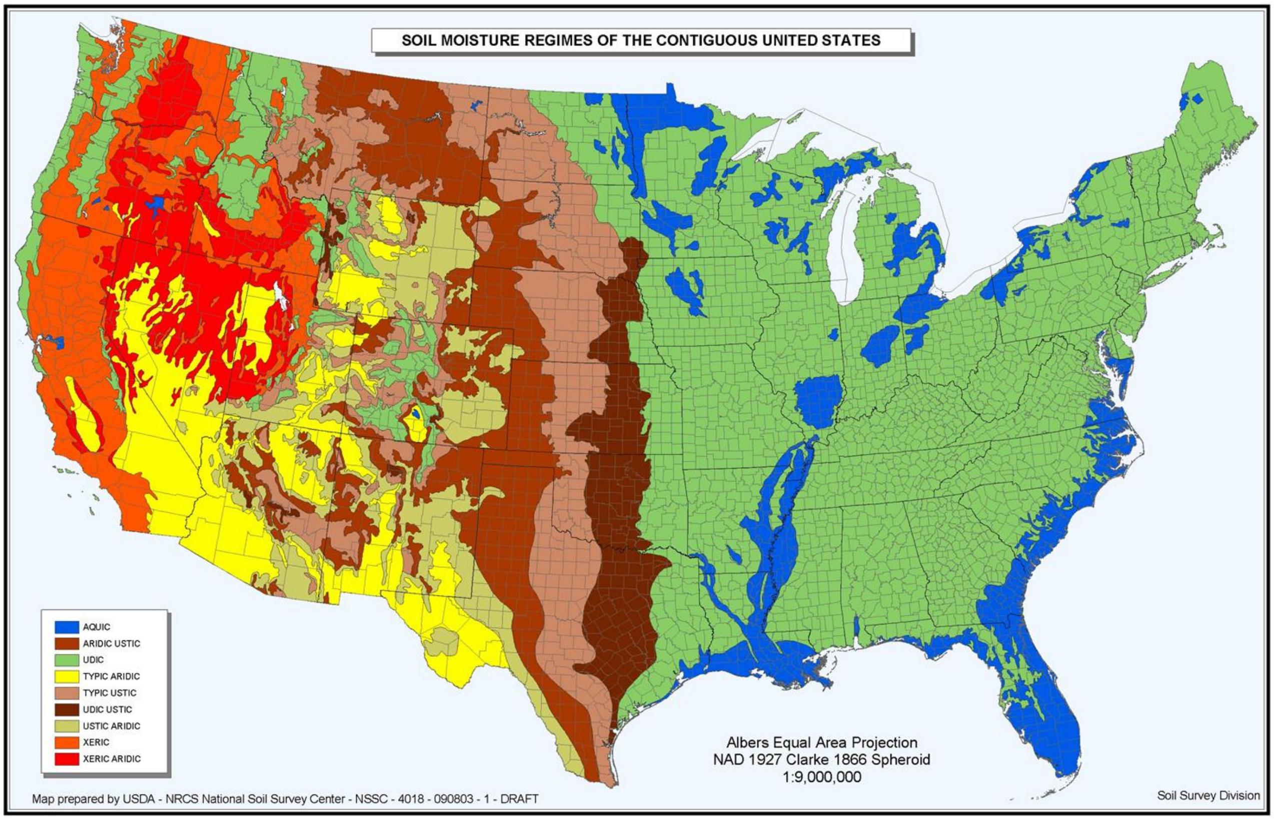

Figure 9: Soil moisture regimes of the contiguous United States from the US Department of Agriculture Natural Resources Conservation Service (USDA NRCS, 2021).

50°F). It is also important to address the lack of stations along the eastern edge of the region (MN, IA, MO) and the implications on the interpolation results in those areas. As previously mentioned, these stations act to help control the edge effects along the main area of study. However, users in these areas can also use the dot maps provided on the website to obtain direct data calculated from the stations themselves, rather than looking at an interpolated estimate, if they are concerned about the robustness of the results in these areas.

This information is also useful for putting spring soil temperatures into context. It helps to answer the question, "How unusual are these soil temperatures for this time of year?" In other words, it provides a baseline to allow agriculturalists to compare the current soil temperatures to what is climatological average. This study is the first of its kind for the area.

5. Conclusions

This study created a soil temperature climatology for the northern and central Plains. Building off a previous study done by Pathak et al. (2012) for Nebraska only, we examined the average Julian day that soil temperature thresholds conducive to successful seed germination and stand establishment were met. This study focused on seven thresholds: 40°F, 45°F, 50°F, 55°F, 60°F, 65°F, and 70°F. Maps were made for each temperature threshold showing a week-long range of Julian days based on at least fifteen years of soil temperature data (with the exception of South Dakota, where at least nine years of data were used). Results showed that soil temperatures in south-central Colorado consistently recorded the earliest Julian days that a temperature threshold was reached, while north-central Minnesota consistently recorded the latest Julian days each threshold was reached. Additionally, starting at the 50°F threshold, a lagging effect began to take place from Minnesota southward into Iowa and northern Missouri. A possible explanation for this effect is the differences in the soil moisture regime. Generally, wetter soils are found in eastern North Dakota, Minnesota, Iowa, and Missouri while drier soils are found in South Dakota, Nebraska, Kansas, and areas westward. These moisture differences could affect how quickly soils heat up in the spring with wetter soils taking longer. Additionally, variations in air temperature and snow cover could also play a role.

The soil temperature climatology tool created from this study can be used by both large-scale farmers and local home gardeners to make informed planting decisions and provide a climatological baseline for putting current soil temperatures into context. Future work with this project could go many ways. First, this study could be expanded to the east to include Midwestern states, which is another region of high agricultural productivity. Next, a study could be done exploring the trends in the Julian days for each threshold, specifically looking for how they may change from one decade to the next. Additionally, as the period of record of automated stations grows, this study could be recreated in the future to include additional stations, which would provide a more detailed look at the region and add to the robustness of the climatology, especially in data-sparse areas. Building on the previous idea, as more automated stations gather a longer period of record, an analysis could be done to look at 1-in-10 year and 9-in-10 year dates for soil temperatures.

REFERENCES

Agri learner. (2018, November 11). Soil Moisture Regimes. Agri learner. http://www.agrilearner.com/soil-moisture-regimes/.

Clarke, S. J., Lamont, K. J., Pan, H. Y., Barry, L. A., Hall, A., & Rogiers, S. Y. (2015). Spring root-zone temperature regulates root growth, nutrient uptake and shoot growth dynamics in grapevines. Australian Journal of Grape and Wine Research, 21(3), 479–489. https://doi.org/10.1111/ajgw.12160

ERSI (2020). How kriging works. How Kriging works-ArcGIS Pro | Documentation. Retrieved June 19, 2020, from https://pro.arcgis.com/en/pro-app/latest/tool-reference/3d-analyst/how-kriging-works.htm.

Gavito, M. E., Curtis, P. S., Mikkelsen, T. N., & Jakobsen, I. (2001). Interactive effects of soil temperature, atmospheric carbon dioxide and soil N on root development, biomass and nutrient uptake of winter wheat during vegetative growth. Journal of Experimental Botany, 52(362), 1913–1923. https://doi.org/10.1093/jexbot/52.362.1913

Grundstein, A., Todhunter, P., & Mote, T. (2005). Snowpack control over the thermal offset of air and soil temperatures in eastern North Dakota. Geophysical Research Letters, 32(8). https://doi.org/10.1029/2005gl022532

Hu, Q., & Feng, S. (2003). A Daily Soil Temperature Dataset and Soil Temperature Climatology of the Contiguous United States. Journal of Applied Meteorology, 42(8), 1139–1156. https://doi.org/10.1175/1520-0450(2003)042<1139:adstda>2.0.co;2

Kaspar, T. C., & Bland, W. L. (1992). Soil Temperature And Root Growth. Soil Science, 154(4), 290–299. https://doi.org/10.1097/00010694-199210000-00005

Lahti, M., Aphalo, P. J., Finer, L., Ryyppo, A., Lehto, T., & Mannerkoski, H. (2004). Effects of soil temperature on shoot and root growth and nutrient uptake of 5-year-old Norway spruce seedlings. Tree Physiology, 25(1), 115–122. https://doi.org/10.1093/treephys/25.1.115

Maurer, G. E., & Bowling, D. R. (2014). Seasonal snowpack characteristics influence soil temperature and water content at multiple scales in interior western U.S. mountain ecosystems. Water Resources Research, 50(6), 5216–5234. https://doi.org/10.1002/2013wr014452

Onwuka, B., & Mang, B. (2018). Effects of Soil Temperature on Some Soil Properties and Plant Growth. Advances in Plants & Agriculture Research, 8(1), 34–37. https://doi.org/10.15406/apar.2018.08.00288

Oschner, T. (2019). Soil Thermal Properties. Version (3). In Rain or Shine. https://open.library.okstate.edu/rainorshine/chapter/13-2-soil-thermal-properties/.

Pathak, T. B., Hubbard, K. G., & Shulski, M. (2012). Soil Temperature: A Guide for Planting Agronomic and Horticulture Crops in Nebraska. NebGuide.

Prasad, P. V., Boote, K. J., Thomas, J. M., Allen, L. H., & Gorbet, D. W. (2006). Influence of Soil Temperature on Seedling Emergence and Early Growth of Peanut Cultivars in Field Conditions. Journal of Agronomy and Crop Science, 192(3), 168–177. https://doi.org/10.1111/j.1439-037x.2006.00198.x

U.S. Climate Resilience Toolkit. (2021). Northern Great Plains. Northern Great Plains | U.S. Climate Resilience Toolkit. Retrieved October 29, 2021, from https://toolkit.climate.gov/regions/northern-great-plains.

USDA NRCS. (n.d.). Soil Moisture Regimes of the Contiguous United States. USDA Natural Resources Conservation Service. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/maps/?cid=nrcs142p2_053997.

Wang, S. L., Mosheim, R., Nehring, R., & Njuki, E. (2020, November 17). Agricultural Productivity in the U.S. Retrieved from USDA Economic Research Service: https://ers.usda.gov/data-products/agricultural-productivity-in-the-us/

Zhu, S., Chen, H., Dai, Y., Lu, X., Shangguan, W., Yuan, H., & Wei, N. (2021). Evaluation of the Effect of Low Soil Temperature Stress on the Land Surface Energy Fluxes Simulation in the Site and Global Offline Experiments. Journal of Advances in Modeling Earth Systems, 13(4). https://doi.org/10.1029/2020ms002403

ACKNOWLEDGEMENTS

The authors would like to give a special thanks to William Sorensen for writing the Python script used to create the climatology. We would also like to thank our partners at the USDA for feedback on this project as it was being developed. Additionally, we gave thanks to the anonymous reviewers who helped edit and review this manuscript for publication.