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Shifts in Crop and Grassland Incidence in the US and Canada: What Have We Seen and What May Be Driving the Movement

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Abstract

Crop and grassland production incidence across the United States and Canada has shifted. We document shifts in land allocation from the late 1970s to the early 2020s for ten crops and two grassland types. We find cold-tolerant crops (canola, oats, barley, alfalfa, and spring wheat) shifted northward and westward into Canada. Warm-season crops (corn, soybeans and sorghum) also expanded northward and westward to some extent, leaving the south and east. Cotton, as a heat-tolerant crop, shifted southward and eastward. There are a number of likely reasons for these shifts. Warming winters and longer growing seasons in northwestern Canada are consistent with the expansion of cold-tolerant crops, while rising extreme heat and declining precipitation are consistent with grain crop retreat in the US Southeast. Beyond climate, the US Renewable Fuel Standard drove acreage expansion in corn and soybeans, while canola oil demand expansions stimulated canola production increases across the Canadian prairies. Places where crops have expanded mostly exhibit high relative current yields tracking locational comparative advantage. Because much of this expansion lies in Canada, a US-only view would record retreat and miss compensating across countries. Our findings reveal a reshaping of North American agriculture with climate and RFS demand as two major forces.

Introduction

Efficient, resilient, and geographically dispersed agricultural production is essential to sustaining local, national and global food/feed supplies. In recent decades, spatial shifts in the location of crop and grassland production have become increasingly evident, altering some local food and feed supplies. Some regions are losing suitability for traditional crops and grasslands, while others are gaining productive potential. Potential drivers behind these spatial shifts include climate, policy, and technology. In this paper, we explore crop and grassland geographic shifts across the United States and Canada, comparing observed production locations between the late 1970s and the early 2020s. We also investigate potential drivers of the observed shifts.

Crop and grassland incidence has been shifting across the landscape as existing crops lose regional suitability and new ones gain it. Crop incidence movements have been documented globally including in North America[1–7], Europe[8,9], China[10–12] and Africa[13,14]. Major production zones for many crops have shifted to higher latitudes, higher elevations, or both.

Climate change is frequently cited as a driver of these shifts[4,6–12]. Adaptation through crop mix shifts is a way farmers accommodate the changing climate. Such adaptations have characterized agricultural systems for centuries. However, climate change is now accelerating and is having implications for regional crop suitability and this is expected to continue for the foreseeable future[15]. This is particularly relevant for the period from now through mid-21st century that the Intergovernmental Panel on Climate Change (IPCC) has termed the “era of committed climate change”[16].

Our study differs from previous crop mix shift studies in several major ways. Most prior studies of crop mix shifts have used either an econometric or a geographic-characteristics approach and have concentrated on a small set of crops. In this paper, we employ a map-based approach to document shifts in the incidence of ten crops and two grassland types across the United States and Canada, comparing production locations between the late 1970s and the early 2020s. This captures substitution patterns between crops and grasslands that single-commodity or single-country studies cannot detect. We also examine potential drivers of these shifts, focusing primarily on climate, relative yields, market and policy developments while briefly discussing other potentially influential factors.

Results

We compare shifts in crop and grassland geographic incidence across the United States and Canada between two three-year windows, 1976–1978 and 2020–2022. We do this using county-level data from USDA Quick Stats and the Canadian Census of Agriculture (see Methods). We characterize geographic shifts using two complementary measures. The first is the harvested-area-weighted centroid[1,3,4]. The second is a constructed major production area (MPA) boundary, that is comprised of top-producing counties whose cumulative output accounts for 80% of total combined US-Canada production. We illustrate both measures for soybeans before using a more summarized presentation for the other crops and grasslands.

A focus on soybeans

Soybeans provide a compelling case study, as its incidence exhibits substantial shifts within both the United States and Canada. Figure 1a and 1b show the county geographic distribution of all reported soybean harvested areas in 1976–1978 and 2020–2022. They reveal a northwestward shift in soybean harvested area with expansions in the Dakotas, Minnesota, Manitoba, and Ontario, alongside reductions in Texas, Louisiana, Alabama, Mississippi, Georgia, and the Carolinas. In terms of harvested-area-weighted centroid, Fig. 1c portrays the northwestward centroid movement, showing that in nearly 40 years, the centroid of production has moved from south-central Illinois to southeastern Iowa, comprising a 310 km shift northward and a 133 km shift westward with a strong movement into Canada (Extended Data Table 1). Figure 1d overlays the major production areas (MPAs) during the two periods, with blue shading for the 1976–1978 MPA, red shading for the 2020–2022 MPA, and purple where the two overlap. It reveals the northwestward expansion into new counties as seen in red, and the retreat of the MPA from southern counties in blue and is reflective of the shift observed in Figs. 1a and 1b. We further note that harvested area gains exceed the losses as shown in Extended Data Table 2. In particular the total US-Canada harvested soybean area increased by 58%, with the increase exceeding 1,200% in Canada and 50% in the United States. Below the MPA and centroid movements maps will be used to describe shifts for all crop and grassland types.

Shifts in crop incidence for all crops

Figure 2 and Fig. 3 present centroid movements and MPA boundary shifts from 1976–1978 to 2020–2022 for all the crops we analyzed. In both figures, crops are arranged in rows according to their historical growing regions, with those grown in more northern areas occupying the top row and those grown in more southern regions occupying the bottom row. Within each row, crops are ordered from left to right based on increases in southern incidence.

Figure 2 reveals northward and westward centroid shifts for most crops, with canola, winter wheat, and cotton being the exceptions (numerically shown in Extended Data Table 1). The canola centroid shifts southeast within Canada, a pattern likely attributable to the large increase in canola production in the southern Canadian prairies. Winter wheat exhibits a northeastern shift, while cotton shows a strong eastward shift with a modest southward component.

Figure 3 exhibits the MPAs, offering more insights into the shifts. For all crops but canola in the top row, MPA boundaries shift northward and westward, extending into Alberta and, in some cases, British Columbia. The Canola MPA moves both northwest and southeast, showing the largest percentage increase in harvested area among these crops over the period (Extended Data Table 2). This broad area MPA expansion in both directions across the Canadian prairies is masked by the centroid that only shows shifts southeast. Barley and oats exhibit the most pronounced contractions in both MPA range and harvested acreage, with particularly sharp reductions within the United States (Extended Data Table 2). Spring wheat also declines in both countries, though to a lesser degree. Alfalfa presents a mixed pattern, contracting in the United States while expanding in Canada, with a net northward redistribution of its MPA.

Among the more southern crops (bottom row), soybeans display the patterns described above. Corn shows a similar northwestward shift accompanied by a retreat from the Southeast. For winter wheat, the MPA boundary remains largely unchanged over time, with the primary exception being a shift out of California that likely accounts for the eastward component of its centroid. However, its harvested area declines substantially across the region. Sorghum moves northwest, with the MPA concentrating in the southern Great Plains. Finally, upland cotton expands into Alabama, Georgia, South Carolina, and North Carolina while retreating from California, where upland varieties are being replaced by Pima varieties not covered here; this pattern partly reflects cotton replacing corn and soybeans in the Southeast as those crops move out.

Shifts in grassland incidence

We now turn to shifts in grassland incidence, covering two categories: harvested other (non alfalfa) hay and grazed pastureland. Pasture also includes what is commonly classified as rangeland, including land designated for public grazing.

For other hay, Figs. 4a and 4b present centroid movement and MPA boundary shifts, respectively. The centroid exhibits a southwestward shift. A closer examination of the MPA reveals shifts in both eastward and westward directions, illustrating a limitation of relying solely on centroids. In particular, the centroid masks opposing shifts that are roughly equal in magnitude. In this case, the westward shift slightly outweighs the eastward shift, so the centroid registers a net westward movement even though the MPA expands in both directions. The MPA also shifts somewhat to the southeast, partially into areas vacated by corn and soybeans. This other hay pattern likely reflects the widespread adoption of the large round hay baler in the early 1970s.

For pastureland, we decided that this analysis should not rely on land areas alone but must account for the heterogeneity of grazed pasturelands in terms of animal-unit stocking rates. One cow-calf animal unit requires as much as 30–40 acres in the arid western US and as little as 1.5-2 acres in the wetter eastern US. We therefore compute county-level animal units (AUs) following Mu et al.[17], converting livestock counts from USDA and Canadian surveys to AU equivalents and aggregating to county totals. The resultant AU-based centroid (Fig. 4c) exhibits a weak northward and westward shift, with MPA boundaries overlapping substantially across the two periods (Fig. 4d). The MPA overlay reveals retreats from areas in California and Arizona, east of the Mississippi River, parts of the Southeast, and western Alberta, alongside additions in British Columbia and northern Alberta.

Climate pattern changes and the crop shifts

A large body of literature has addressed the impacts of climate on crop yields, and to a lesser extent, effects on regional crop mix. Temperature and its characteristics have been well studied as a driver, with recent work focusing largely on growing-season (GS) degree days[18,19] typically using degree days grouped into classes such as cold, moderate, and extreme[20,21]. Most temperature-focused studies find that degree days in a moderate temperature range are favorable, while conditions become less favorable when temperatures fall into high or low ranges. Overall, the evidence indicates that an inverted-U shape best characterizes the response of crop yields to temperature.

Beyond temperature, studies have examined precipitation effects, including the total amount of precipitation, which again exhibits an inverted-U-shaped effect on crop yields, along with the share of rainfall coming from the wettest days and the effects of drought or extreme wet conditions [22–25].

Based on prior studies we chose to examine the geographic incidence of eight key climate changes over time (see Methods Section for how we formed these measures). Four are temperature-based degree-day measures: extreme cold

in the non-GS, and cold, moderate, and extreme heat during the GS. Two describe precipitation: the total amount over the GS and its intensity, measured as the share falling on the wettest days over the total precipitation in the GS. The remaining two, based on the Palmer Drought Severity Index (PDSI), capture how often conditions reached moderate-to-extreme drought and moderate-to-extreme wetness. Figure 5 maps differences between the two periods in these climate variables that influence crop production. The maps reveal substantial spatial heterogeneity across the continent, and we choose to discuss the effects for several selected regions. Extended Data Fig. 1 shows a map of the regions we discuss.

For Northern British Columbia and Alberta (region a in the Extended Data Fig. 1), we observe decreases in both extreme winter cold and GS cold degree days, an increase in moderate GS degree days, little change in total precipitation or precipitation intensity, small changes in drought frequency, and an increase in moderate-to-extreme wet conditions. Over the same period, we see MPA expansions for spring wheat, barley, oats, canola, alfalfa, and pastureland (Fig. 3). Collectively, these patterns suggest that climate conditions in this Canadian area are becoming more favorable for crops, consistent with the substantial expansion of cold-tolerant crops observed.

For Lower Ontario (region b), the land area situated between Lakes Huron, Erie, and Ontario, we observe a small reduction in GS cold degree days, an increase in GS moderate degree days, and no change in GS extreme heat degree days. For precipitation, parts of the region receive more rainfall alongside a small reduction in precipitation intensity, a reduction in drought frequency, and mixed results in moderate-to-extreme wet conditions. Simultaneously, the MPA changes show declines in oats and pastureland grazing animals, mixed results for alfalfa, and expansions into this northern area for soybeans, winter wheat, and corn. Overall, these shifts point to more favorable conditions for warm-season crops, allowing corn, soybeans, and winter wheat to expand while displacing cool-season crops and pastureland through land competition.

For Minnesota and the Dakotas (region c), Fig. 5 shows a decrease in non-GS cold degree days and minor changes in GS degree days across all categories. For moisture, total precipitation generally declines across the region, with mixed results in precipitation intensity, minor changes in drought frequency, and a slight increase in moderate-to-extreme wet conditions in parts of the region. Simultaneously, we see reductions in spring wheat, barley, oats, and other hay, along with expansions for soybeans and corn. Overall, climate does not appear to be a major driver here. The observed shifts are more likely the result of corn and soybean production expansions, as we discuss below.

For Texas (region d), GS moderate degree-days decrease, and extreme heat degree-days increase. In the central and western portions of the state, where most of the cropping occurs, total precipitation declines and precipitation intensity rises. Drought frequency also increases, indicating lower and more variable moisture in the major cropping areas. For the MPA, we see small shifts for corn, alfalfa, sorghum, and upland cotton, together with increases in other hay and grazing animals on pastureland, mainly in the northern part of the state. Overall, the MPA shifts reflect a retreat from the hotter and drier central and western areas, accompanied by reduced stocking rates consistent with declining forage production.

Turning to the Central US along the Lower Mississippi River (region e), both drought and wet incidence rise, indicating greater moisture variability, and climate conditions are becoming slightly less favorable for cropping. We see minor MPA reductions for oats, alfalfa, soybeans, winter wheat, sorghum, and grazing animals, along with minor expansions for corn and other hay. Some grazing grasslands are shifting to other hay production, and in some areas, other hay is replacing row crops.

In the US Southeast near coastal parts of the Carolinas and Georgia (region f), we observe slight declines in cold and moderate GS degree days and a slight increase in extreme heat degree days. The MPAs show contractions for corn and soybeans and an expansion for upland cotton. Here, the more heat-tolerant cotton appears to be replacing grain crops,

consistent with the rising incidence of extreme heat. Boll weevil (a cotton pest) control has likely also contributed to this shift[26].

In southern California and Arizona (region g), drier and hotter conditions, together with declining precipitation intensity and rising drought frequency, appear to be pushing cropping out of the region, accompanied by a large expansion in other hay.

For the broader Southeast US, between the Lower Mississippi River and the Atlantic Coast, precipitation is increasing and drought frequency falling, but moderate-to-extreme wet conditions are becoming more frequent. The rising incidence of wet conditions may be reducing suitability for row crops, contributing to the expansion of other hay production observed in this area.

Crop Yield Changes

Cho and McCarl[4] find that climate explains only about half of observed crop mix shifts, leaving substantial room for other contributing factors. Yield-related changes represent another possibility, as they may have shifted relative profitability and influenced farmers' crop choices[27,28]. Such yield effects are shaped by both climate and technological improvements[19,29]. Here we focus on regional yields as they occurred in 2020–2022 relative to the US-Canada average. We do this to isolate locational comparative advantage and examine it in a relative manner for countries entering or exiting the MPAs. In our presentation (Fig. 6), a relative yield of 1.1 indicates crop yield in the county is 10% above the US and Canada production-weighted average (USCANavg).

Canola has expanded into northern Alberta and Manitoba, where yields are roughly equal to the USCANavg, suggesting that the shift in the major producing region did not substantially reduce relative productivity. For barley, oats, and spring wheat, similar MPA expansions are observed into northern Alberta and northern British Columbia, with the MPA yields above or near the USCANavg. These areas achieve their high yields despite predominantly dryland production, owing to higher precipitation relative to southern Alberta and Saskatchewan[30], where dryland crop yields are low. For barley and oats, US production areas have contracted substantially, with retained production concentrated in comparatively higher yielding irrigated counties.

Turning to the warm-season crops, the soybean MPA has expanded into western and southern Ontario, where relative yields are high, and simultaneously into areas in Minnesota, the Dakotas, and Manitoba, where relative yields are lower. The expansion into these lower-yielding areas is likely driven by broader acreage growth that was likely induced by biofuel policy. Corn exhibits a similar pattern, with expansions westward into Kansas, southward along the Mississippi River, and into southern Ontario, all areas exhibiting high relative yields. Northward expansions into the Dakotas and Minnesota, where relative yields are lower, are again likely driven by demand expansions under biofuel policy.

For the more heat-tolerant sorghum and cotton, distinct shifts are evident. Sorghum has concentrated in the relatively high-yielding southern Great Plains, while cotton has moved into the Southeast, where relative yields are high, coinciding with a withdrawal from lower-yielding areas of Texas and a contraction in California. However, not all retained hotter-season crops are located in the highest-yield counties, reflecting competition from other crops in some areas, notably wheat in Kansas for sorghum and high-value horticulture in the California Central Valley for cotton.

For grasslands, other hay has expanded into areas in the Southeast and Northwest, where relative yields are high, while production has been retained in East Texas and in some of the Mountain States. For grazing animal AUs, a similar expansion is observed in northern Alberta and British Columbia, where relative yields are high, while contractions are

observed in Arizona and California, where yields are relatively lower. Pastureland stocking rates have also increased in the East, likely reflecting more favorable precipitation, accompanied by an expansion of the MPA.

Change in Total Market Characteristics

Market shifts may also be influencing production locations. Table 1 presents percentage changes in total production, harvested area and real prices by country and crop. There, we see soybean and canola areas show the largest gains, especially in Canada. Corn area also increases substantially in Canada and modestly in the United States. Wheat, barley, oats, sorghum, and alfalfa harvested acreage declines on a two-country total basis. Production declines are smaller than area reductions, reflecting yield gains. Real prices generally show declines, indicating slower growth in demand than in production. Substantial inflation also occurred over the period, with the CPI rising from approximately 60 in 1976–1978 to 271 in 2020–2022.

The acreage shifts in the maps above point to demand-side forces, including the US Renewable Fuel Standard biofuel-related policy, as major drivers of the soybean and corn expansions, alongside more favorable climate conditions in Canada. For grazing animals, declines are observed in both countries. In the US, this trend is consistent with the smaller cattle herd in the 2000s relative to the 1970s. Note, AU and total head comparisons should be interpreted with caution, as cow weights have increased over time, with cows now weighing 1,300-1,400 pounds and calves likewise larger. However, the AUM definition remains unchanged at *'the amount of dry forage a 1,000-pound cow and her unweaned calf will eat in one month'* [31].

Discussion

The location of crops and grasslands across the United States and Canada has shifted substantially over the past four decades. Cold-tolerant crops (canola, barley, oats, and spring wheat) have moved northward and westward, particularly into Canada, while alfalfa has redistributed northward with a net contraction in the United States. Warm-season crops such as corn, soybeans and sorghum have likewise moved northward and westward. Meanwhile, more heat-tolerant crops, such as cotton and other hay, have shifted southward. Specifically, cotton has moved south and east, and other hay southwestward. Pastureland has declined in California and Arizona and expanded in British Columbia and northern Alberta.

Our analysis confirms that past changes in extreme cold and hot degree days, total precipitation, precipitation intensity, drought, and excessive wetness are consistent with the observed shifts in crops and grasslands. Warming winters and longer GSs in northwestern Canada are consistent with the expansion of cold-tolerant crops previously limited by frost risk, while rising extreme heat and declining precipitation in the US Southeast are consistent with the retreat of grain crops and the advance of more heat-tolerant cotton and other hay.

Most of the areas that crops are expanding into exhibit yields at or above the two-country average, while areas that crops are moving out of tend to fall below that average (Fig. 6), indicating that the observed geographic shifts track locational comparative advantage. Northward expansion of cold-tolerant crops into Canada reflects the utilization of climatically improved land that was previously marginal, and yields in those new production areas are generally competitive with other regions. This pattern is only fully visible on the more continental scale. A US-only analysis would register the retreat without capturing the corresponding Canadian expansion and its yield performance.

Beyond climate, the expansion in soybean and corn area has been particularly influential, driven largely by demand-side expansions under the RFS. For example, the share of corn used for ethanol rose from roughly 3% to approximately 40%, while vegetable oil use for biodiesel and renewable diesel expanded more than sixfold. Rising canola oil demand,

reinforced by Canada's Renewable Fuels Regulations, similarly drove the large-scale expansion of Canadian canola. These biofuel policies have thus influenced the North American agricultural map, and future demand-side policies affecting bioenergy, trade, or food systems may well carry additional geographic consequences. A number of other forces have also contributed, including land-related developments, policy influences, demand shifts, technological advances, resource availability, and other climate channels. Additional discussion on these points is provided in the Supplementary Information.

Our findings carry direct implications for food system resilience and policy. Regions losing historically grown crops (the US Southeast for grains, Texas for cotton) face adjustments in agricultural infrastructure, supply chains, and rural economies. Regions gaining production, particularly in Canada, face corresponding pressures on land and water resources along with increased demands on agricultural and supply chain infrastructure. Our analysis is descriptive and map-based and thus does not firmly establish causality. Establishing the causal magnitudes of individual drivers would require formal identification strategies beyond the scope of this analysis. The reorganization documented here is ongoing: committed climate change through mid-century will continue to cause shifts in production locations, while future bioenergy and trade policies will add further demand-side pressures.

Methods

Data employed

For the United States, county-level crop, animal and grassland area and yield data were obtained from USDA Quick Stats. For Canada, we use the Census of Agriculture and provincial survey data at the Census Division level, which corresponds to municipalities, counties, or census subdivisions, depending on the province, as defined by the Government of Canada shapefile[32]. For simplicity, we refer to the set of regions for which we have data collectively as counties. Climate data are obtained from the ERA5 reanalysis dataset as 0.25° squared grids and then aggregated to the county level weighted by the area. For the Palmer Drought Severity Index, we use the monthly self-calibrated PDSI[33] from the TerraClimate dataset[34], provided at approximately 4 km (1/24 degree) resolution and using Penman-Monteith evapotranspiration in a one-layer water-balance model, then aggregate it to the county level using county area weights. The 1976–1978 window draws on survey data together with the 1976 Canadian Census of Agriculture and the 1978 US Census of Agriculture, while the 2020–2022 window draws on survey data together with the 2021 Canadian Census of Agriculture and the 2022 US Census of Agriculture.

Time windows used

We compare the harvested area and climate data averaged across two three-year windows: 1976–1978 and 2020–2022. These windows were selected because each offer relatively complete data coverage, and the interval between them is sufficiently long to permit substantial readjustment in crop and grassland shares while still showing meaningful differences in climate conditions. Averaging over three years within each window also reduces variation attributable to crop rotation cycles and short-term climate events.

Centroid and major production area definition

The harvested-area-weighted centroid measures the geographic center of production. For each crop and three-year period, we compute it as the weighted mean of county geographic longitude and latitude centroids, where county harvested area share relative to total production across the two countries is used as the weight, following procedures used in the prior literature[1,3,4].

The MPAs for each crop are constructed by ranking total production for all the US and Canadian counties from largest to smallest and then forming the MPA by successively adding counties until the cumulative production total reaches

80% of combined US-Canada production. We construct MPAs separately for each of the two periods (1976–1978 and 2020–2022) and map the resulting boundaries with blue shading for 1976–1978 and red shading for 2020–2022 in all MPA maps in Figs. 1, 3 and 4. In turn, counties that fall in the MPAs in both periods appear in purple, counties newly entering the MPA appear in red, and counties exiting the MPA appear in blue.

Grassland animal unit computation

County-level animal units (AUs) are computed following Mu et al.[17], converting livestock counts from USDA and Canadian surveys to AU equivalents and aggregating to county AU totals. The measure includes AUs from cattle, sheep, and goats, excluding animals on feed and dairy animals, as these species are typically confined and fed from crops and other hay rather than grazed on pasture. Poultry and hogs are not included for the same reason. Steers and heifers in stocker grazing operations are also excluded, since the USDA does not report their numbers at the county level. They account for a small share of grazing, as many spend little time on pasture. Cow-calves, sheep, and goats thus cover most of the animals that graze, which is as complete a measure as the available county-level data allow. The centroids, yields in AUs per acre and MPAs for pasture are then constructed based on county-level AUs.

Climate measures extracted

For each 0.25-degree pixel in the ERA5 dataset, we extracted monthly temperature and precipitation values during the two three-year windows, separately for the summer GS (April-October) and the non-growing-season (November to the next March). We computed shifts in six climate measures: 1) cold non-GS degree days below − 20°C; 2) cold GS degree days with temperatures below 10°C; 3) moderate GS degree days in the temperature band from 10 to 30°C; 4) extreme-heat GS degree days with temperatures above 30°C; 5) total GS precipitation; 6) rainfall intensity, expressed as the share of GS precipitation falling on the 10% of the wettest days;

We added two more climate variables for drought and wet conditions based on the Palmer Drought Severity Index (PDSI): 7) the proportional frequency of months under moderate to extreme drought (PDSI ≤ − 2); and 8) the proportional frequency of months under moderate to extreme wet conditions (PDSI ≥ 2). PDSI takes into account precipitation supply and potential evapotranspiration demand in its calculation[35,36]. We use the monthly self-calibrated PDSI[33] from the TerraClimate dataset[34]. For each pixel in that data set, we extracted monthly PDSI values for the summer GS (April-October) in each of our two three-year windows (1976–1978 and 2020–2022). We then computed the proportional share of GS months in which the monthly PDSI fell below a drought threshold (PDSI ≤ − 2 for moderate to extreme drought) or exceeded the corresponding wet threshold (PDSI ≥ + 2 for moderate to extreme wet), as well as the difference in these shares between the two periods. Maps of these eight climate measures are shown in Fig. 5. We also made maps of extreme PDSI conditions, but found they did not contribute additional insight, so we are not showing them.

Relative yields

County-level yields for the counties within the United States and Canada MPAs are computed as a three-year average over 2020–2022. Yields are expressed relative to the continental scale production-weighted average across all producing counties in the US lower 48 and Canada. A reported value of 1.1 indicates that the county's crop yield is 10% above the two-country production-weighted averages.

Table 1
Percentage Differences between 1976–1978 and 2020–2022 amounts of Production, Harvested Area, and Real Prices in Canada, the US and the Two-country Total

	Changes in Canada			Changes in the US			Changes in two-country total	
	Production increase	Harvested acres increase	Real 2021$ Price change	Production increase	Harvested acres increase	Real 2021$ Price change	Production increase	Harvested acres increase
Spring Wheat	13.8%	-31.9%	-49.1%	7.9%	-28.7%	-37.9%	11.6%	-30.6%
Winter Wheat	237.7%	75.7%	-51.0%	-17.8%	-46.4%	-43.6%	-11.6%	-44.2%
Barley	-0.2%	-23.8%	-38.9%	-62.9%	-75.4%	-35.7%	-28.7%	-47.3%
Oats	-2.7%	-36.5%	-21.2%	-91.0%	-93.1%	-32.4%	-60.2%	-74.5%
Canola	1887.5%	1192.7%	-54.5%			-54.5%	2066.3%	1312.5%
Alfalfa Hay	-12.6%	16.3%	-41.7%	-40.0%	-37.4%	-11.9%	-36.1%	-26.9%
Soybeans	1934.1%	1248.7%	-59.6%	161.9%	50.1%	-56.3%	174.4%	58.1%
Corn	290.8%	109.5%	-48.9%	114.7%	15.5%	-41.3%	118.5%	17.8%
Sorghum				-55.7%	-61.1%	-34.6%	-55.7%	-61.1%
Cotton				20.3%	-35.3%	-69.2%	20.3%	-35.3%
Pasture		-49.0%			-20.0%			-24.0%
Grazing AUs	-11%			-26.2%			-24.7%	
Other Hay	-48.5%	-33.1%	-22.0%	-2.1%	-15.6%	-21.3%	-12.4%	-18.9%

Note: Harvested area is color-coded where red indicates reductions exceeding 50%, orange indicates reductions of 10% to 50%, green indicates increases up to 50%, and purple indicates increases exceeding 50%.

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Figures

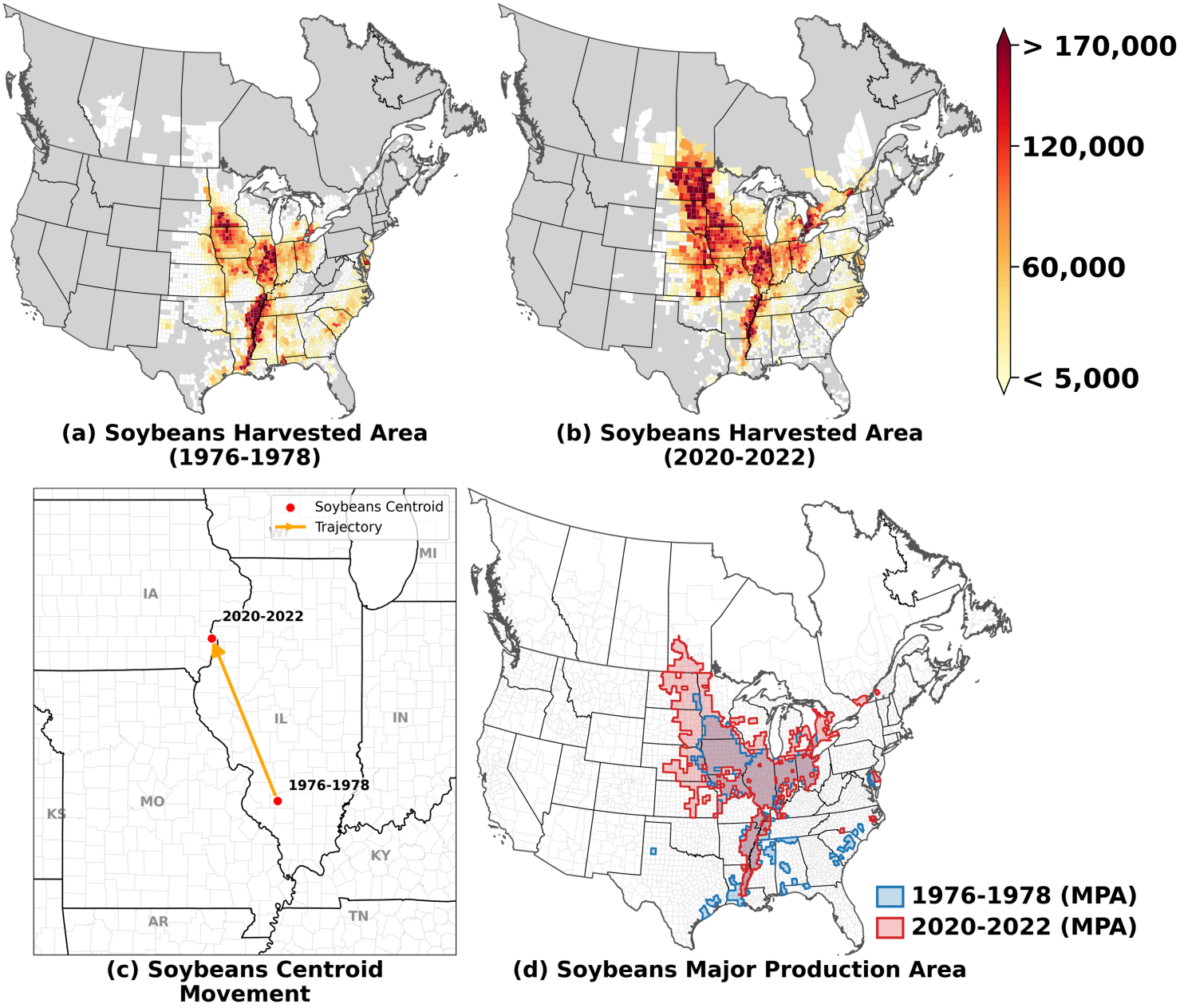


Figure 1

Comparison of soybean harvested area evolution between the late 1970s and early 2020s as distributed geographically in the US and Canada. (a) Average harvested area (acres) in all counties, 1976–1978; (b) average harvested area (acres) in all counties, 2020-2022; (c) evolution of the harvested area centroid from 1976-1978 to 2020-2022; (d) major production areas (MPA) for 1976-1978 (blue), 2020-2022 (red), and their overlap (purple).

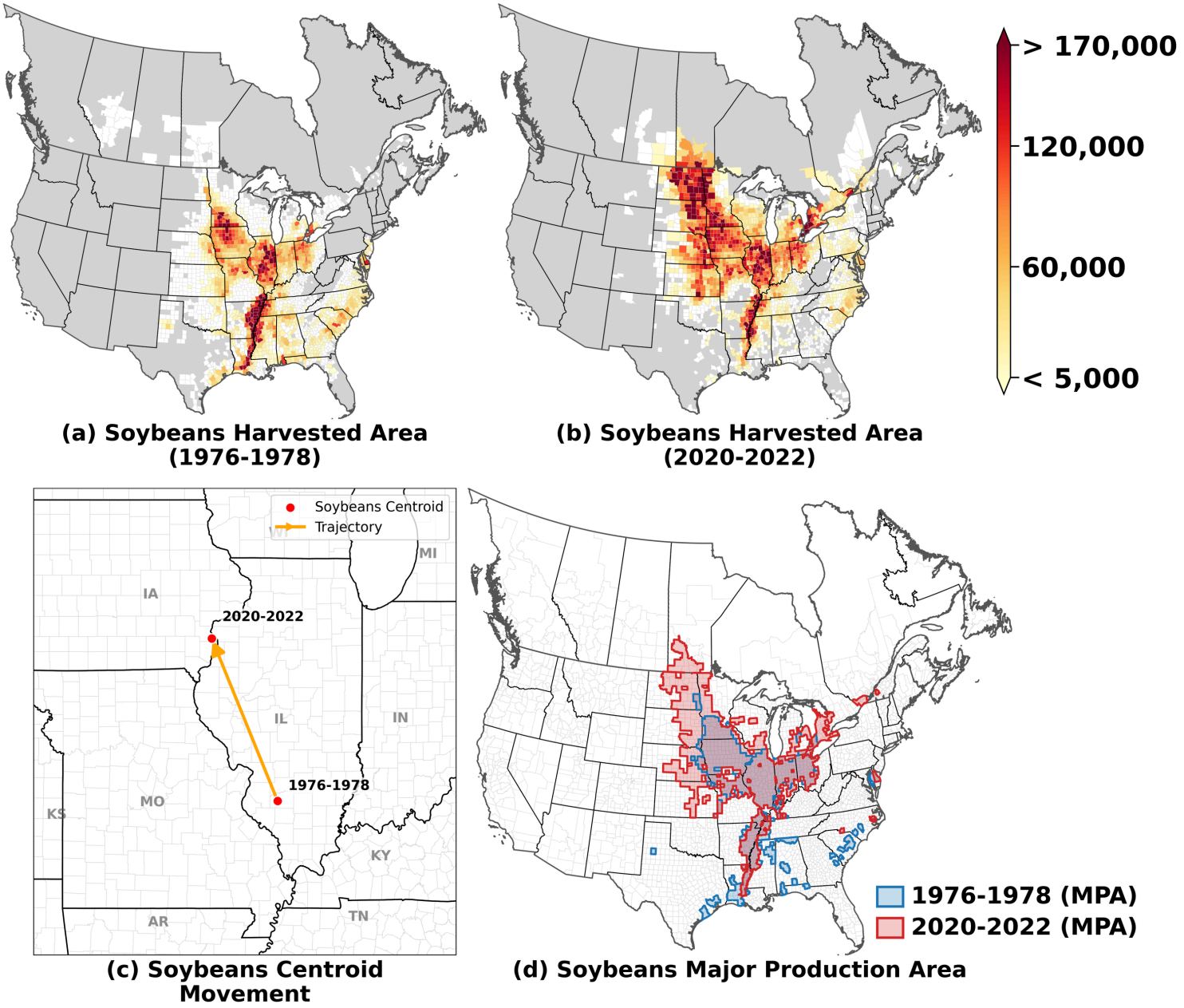


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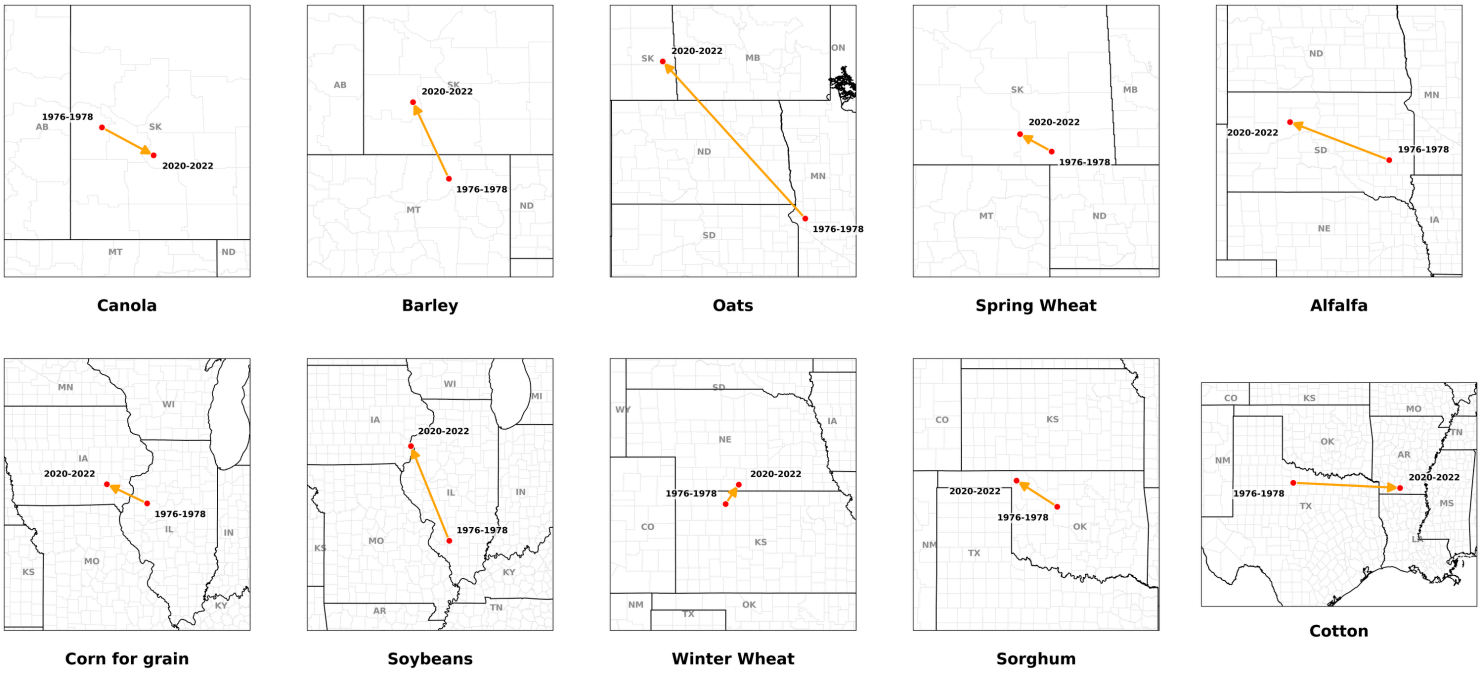


Figure 2

Shifts in Harvested Acreage Weighted Centroid of Major Crops

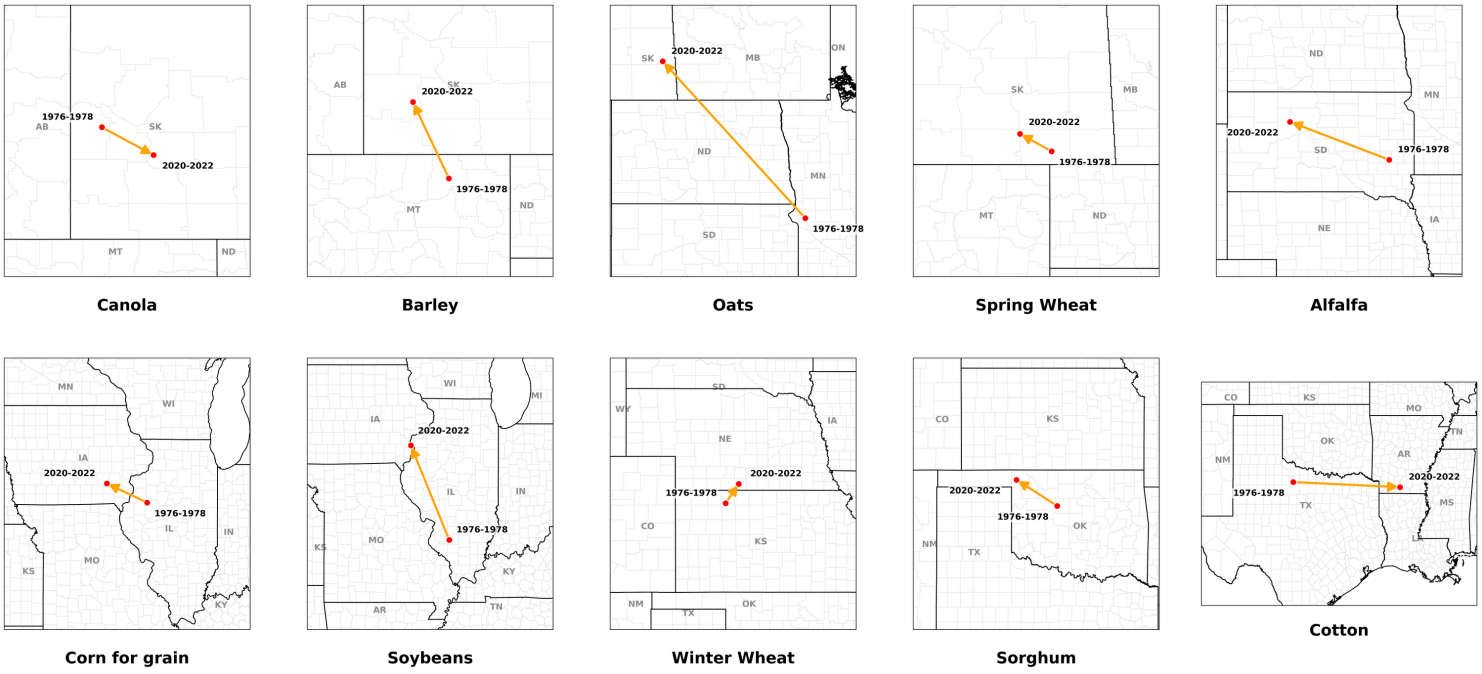


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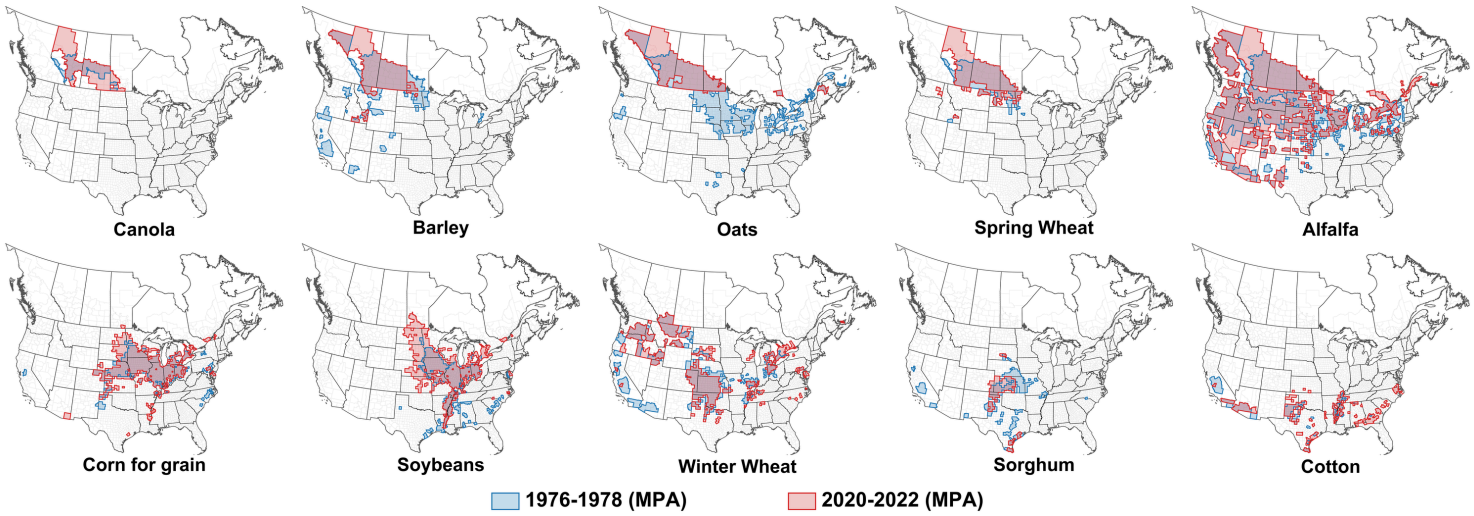


Figure 3

Major Production Area (MPAs) by Crop in 1976-78 (shaded blue) and 2020-22 (shaded red

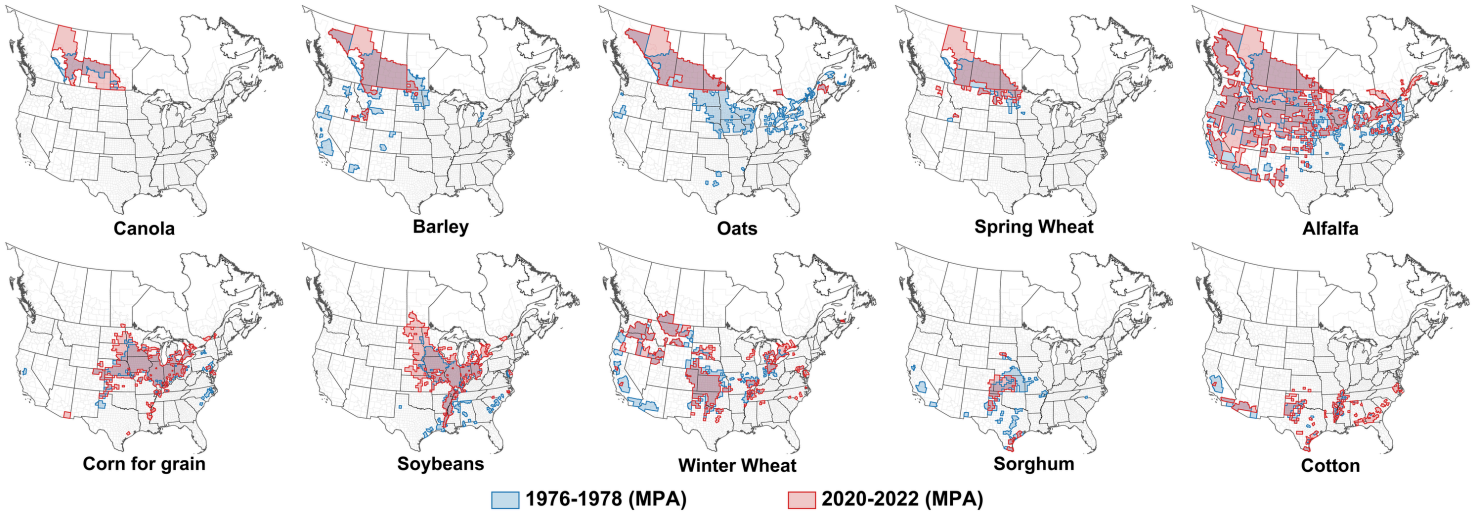


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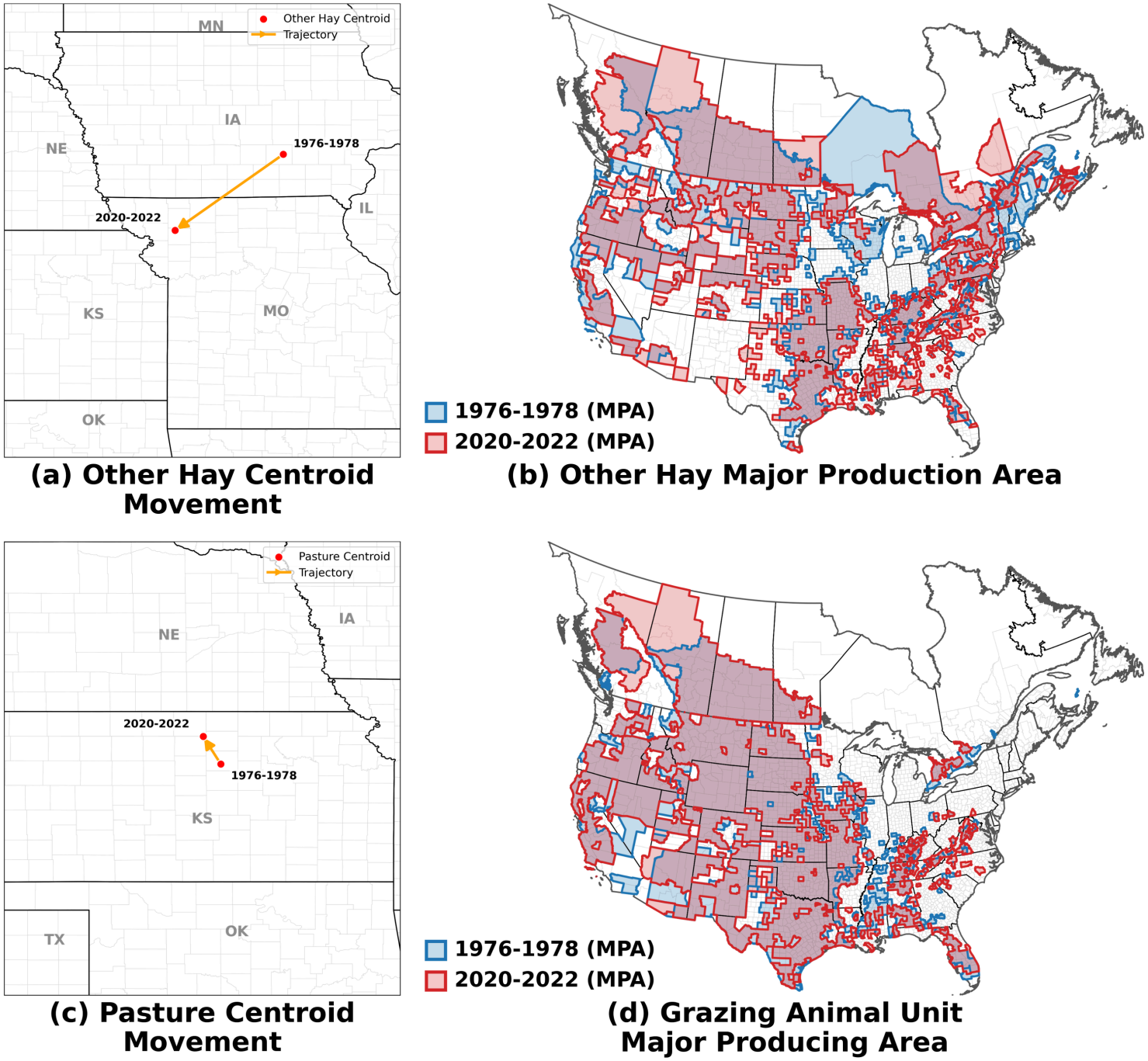
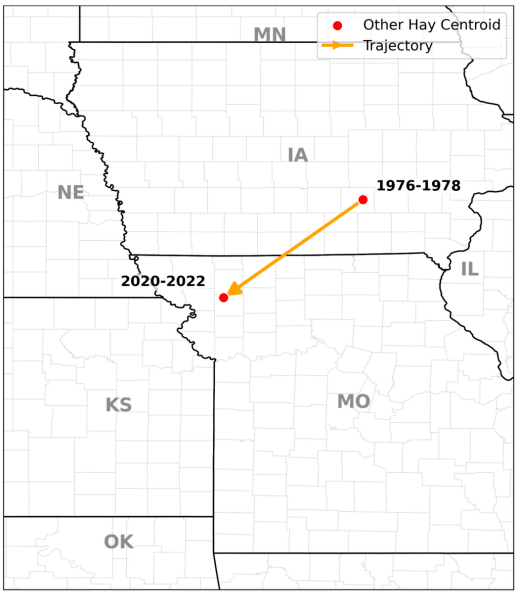
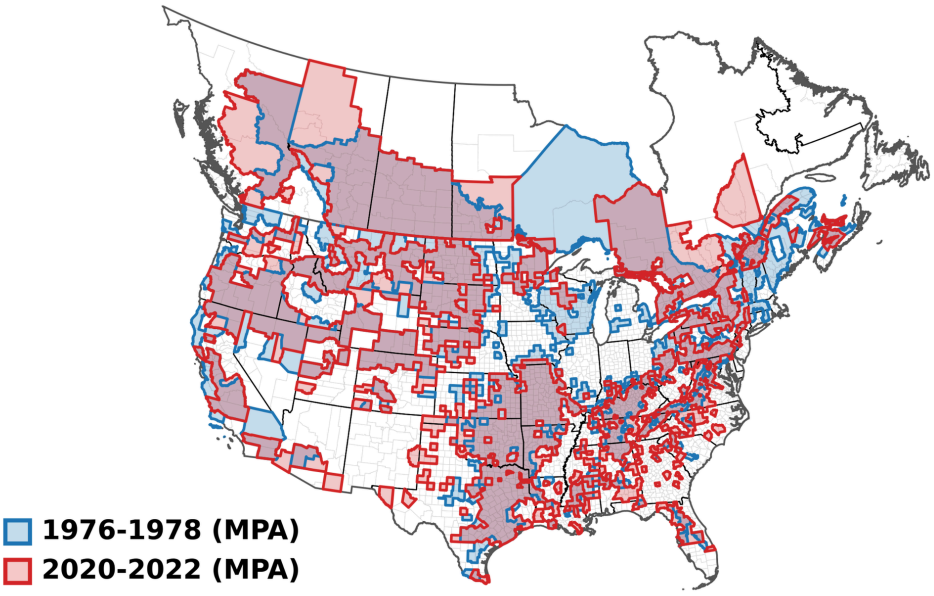


Figure 4

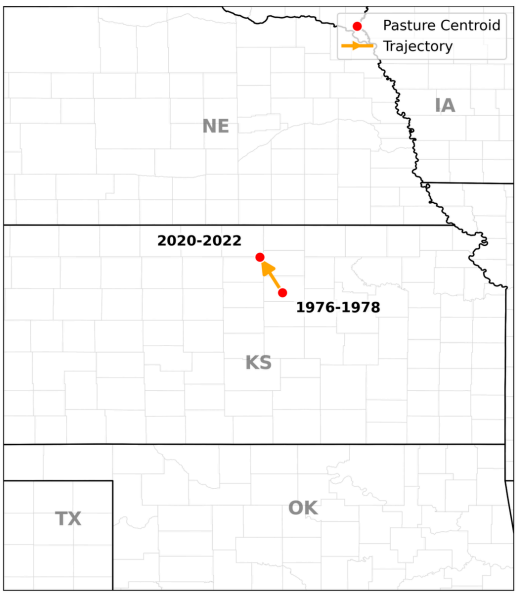
Shifts in producing areas for other hay and pasture, with pasture portrayed in the form of grazing animal unit months. (a) Evolution of the other hay centroid from 1976-1978 to 2020-2022; (b) major production areas (MPA) for other hay: 1976-1978 (blue), 2020-2022 (red), and their overlap (purple); (c) evolution of the AUM-based pasture centroid from 1976-1978 to 2020-2022; (d) major production areas (MPA) for grazing animal units, 1976-1978 (blue), 2020-2022 (red), and their overlap (purple).



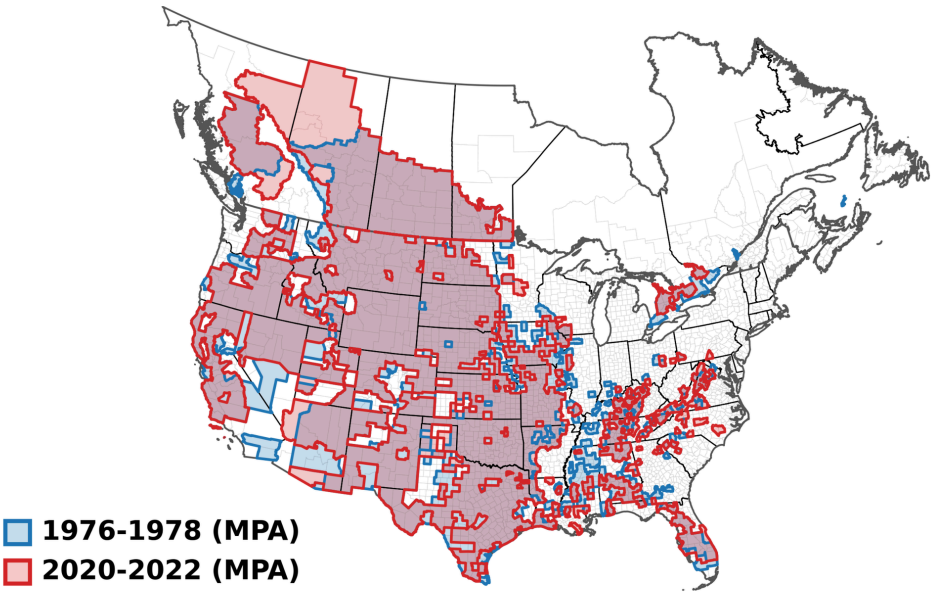
(a) Other Hay Centroid Movement



(b) Other Hay Major Production Area



(c) Pasture Centroid Movement



(d) Grazing Animal Unit Major Producing Area

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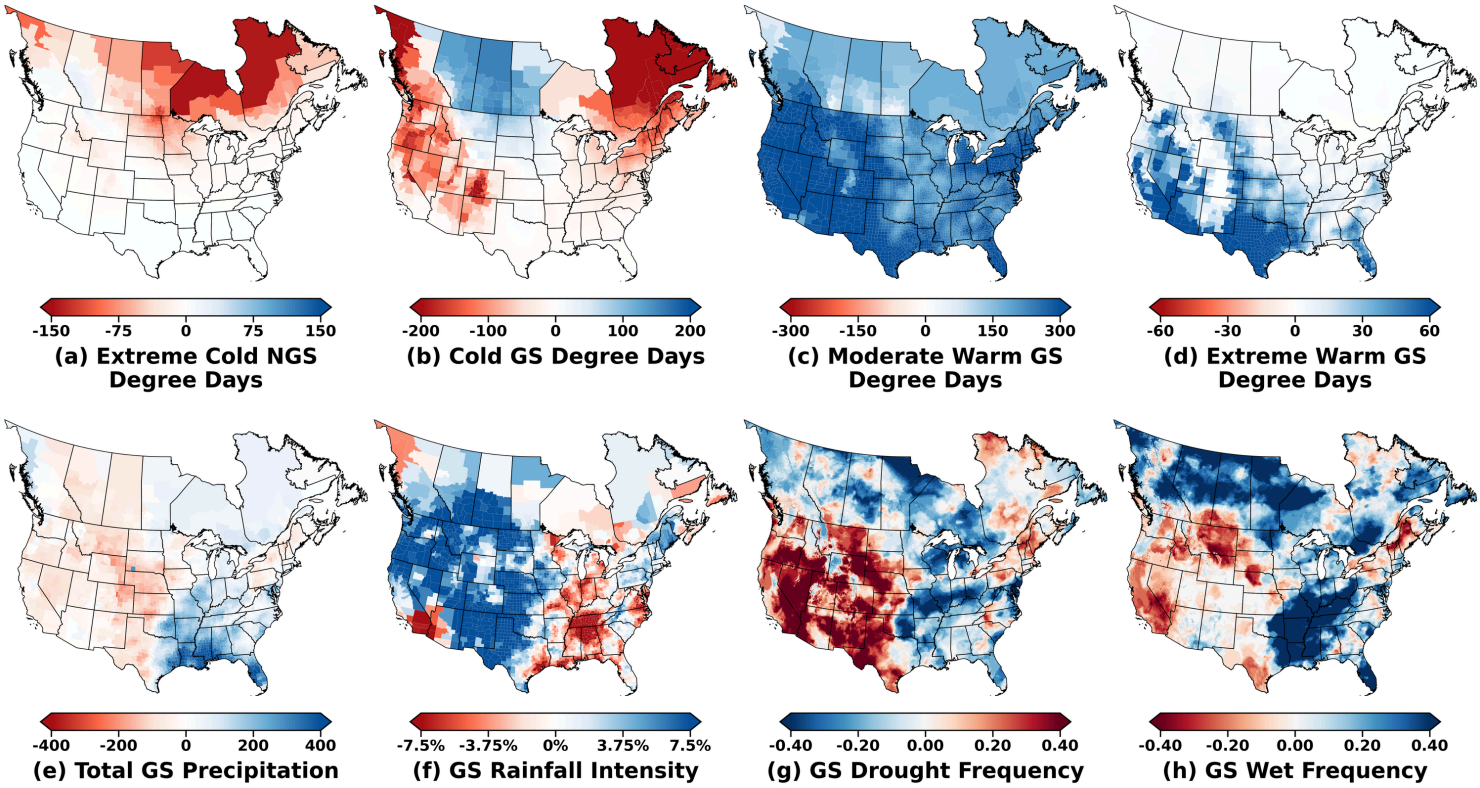


Figure 5

Differences in climate conditions between 1976-1978 and 2020-2022. (a) Change in non-GS cold degree days (DD < -20 °C); (b) change in GS cold DD (< 10 °C); (c) change in GS moderate DD (≥ 10 °C and ≤ 30 °C); (d) change in GS hot DD (> 30 °C); (e) change in GS precipitation (blue denotes more rainfall); (f) change in GS precipitation from the top 10% wettest days (blue denotes more concentrated rainfall); (g) change in the proportion of GS months under moderate-to-extreme drought, PDSI ≤ -2 (red denotes more dry periods); (h) change in the proportion of GS months under moderate-to-extreme wet conditions, PDSI ≥ 2 (blue denotes more wet periods).

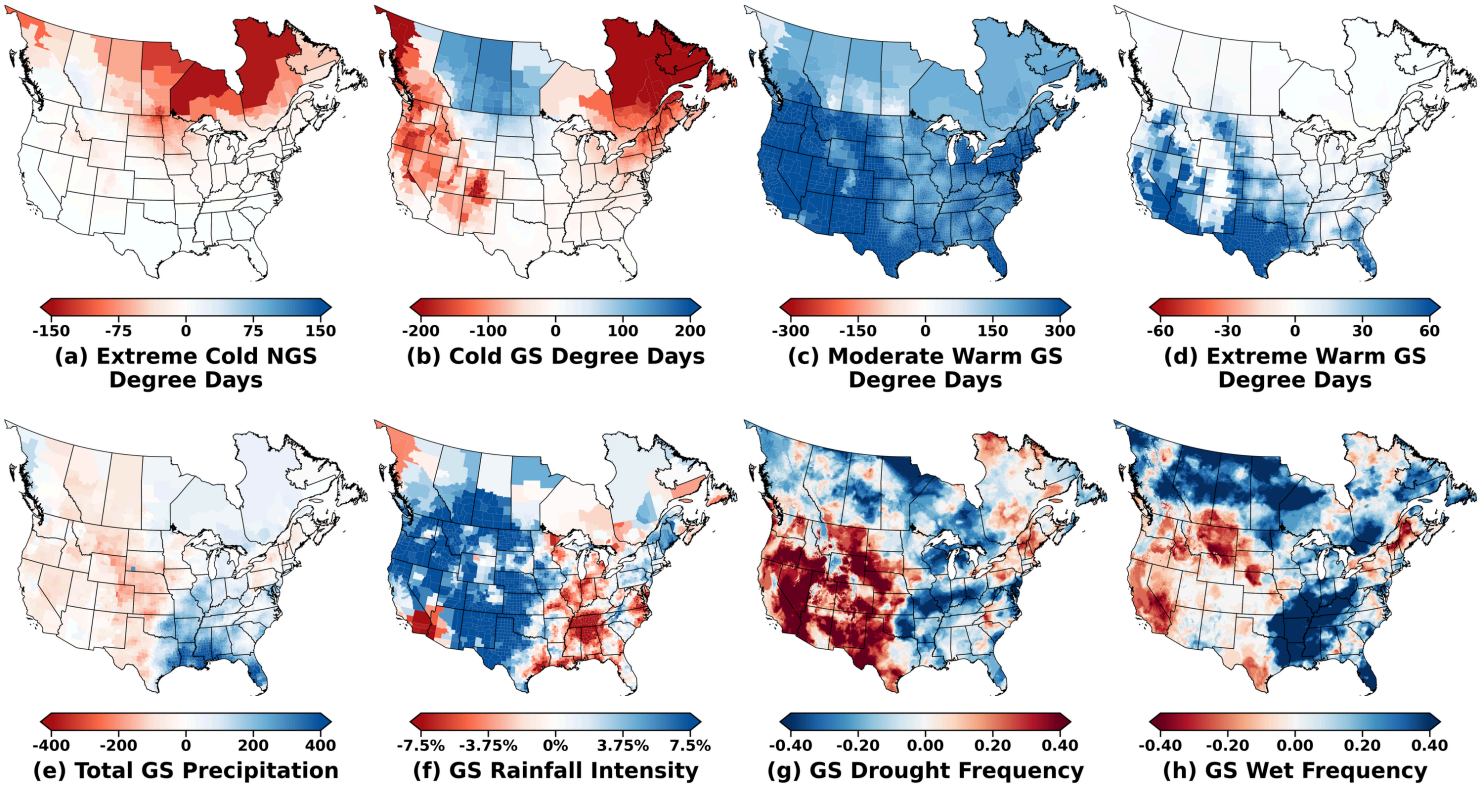


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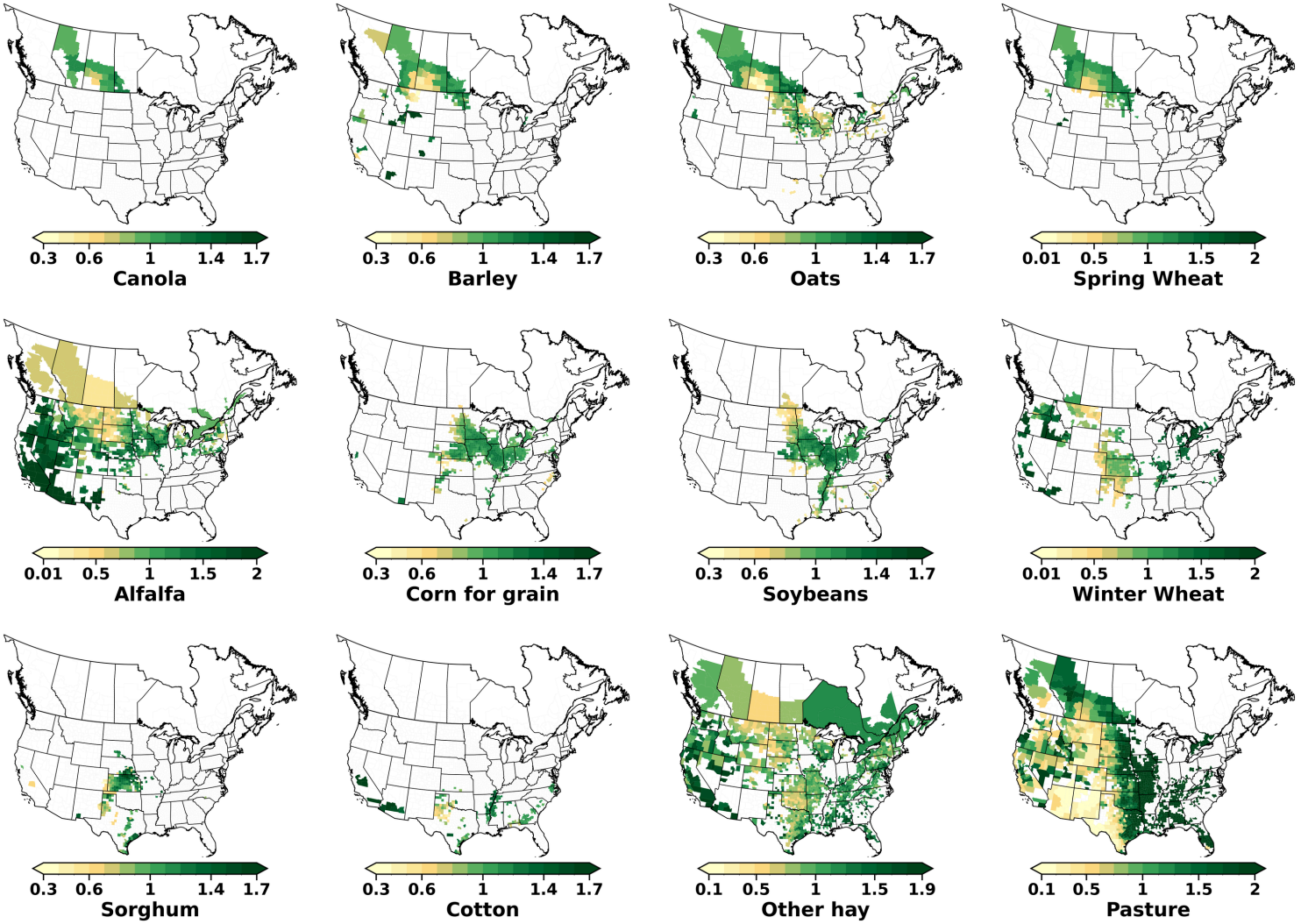


Figure 6

Crop yields relative to the Two-country average in 2020-2022 by counties that fall into our major production areas.

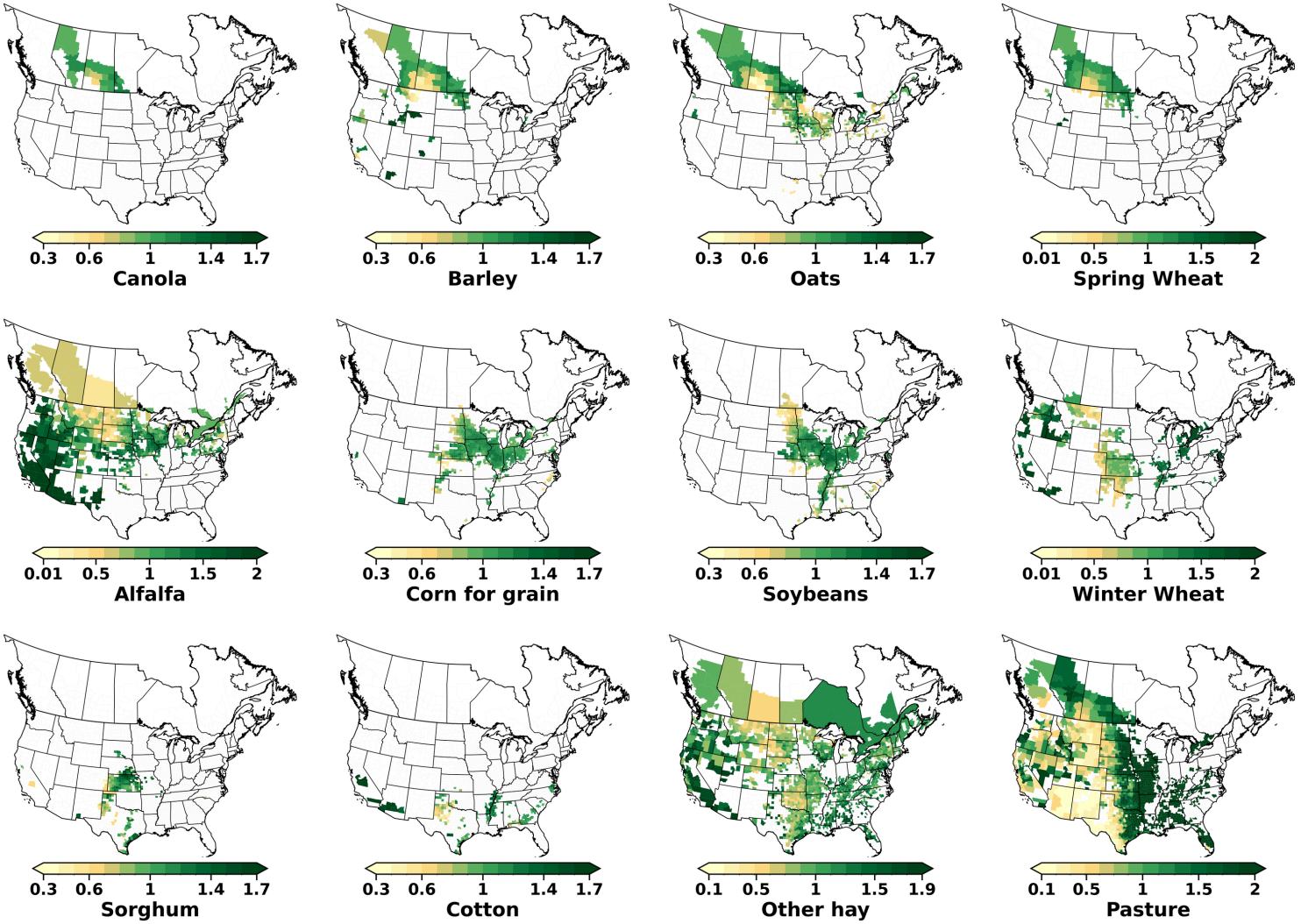


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Crop yields relative to the Two-country average in 2020-2022 by counties that fall into our major production areas.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ExtendedData.docx
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