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Derecho impacts on United States crop condition ratings and yield

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MCS
Mesoscale Convective System
NASS
National Agricultural Statistics Service
PDSI
Palmer Drought Severity Index

ABSTRACT

During most summer growing seasons, corn and soybeans in the United States are impacted by derechos—long-lived, convectively induced windstorms that produce damaging wind gusts over a widespread area. This study employs a storm-tracking algorithm and severe convective wind reports to identify derecho footprints and integrates them with weekly USDA crop condition data to assess changes in corn and soybean conditions and modeled yield over a nine-year period (2015–2023). With county-level yield declines as severe as 37 %, derechos caused condition and yield declines comparable to hurricanes over the historical crop condition period. Overall, 75 % of corn- and soybean-producing counties affected by a derecho experienced a subsequent decline in crop conditions. Derecho frequency maximizes over the Corn Belt, resulting in large potential exposure and crop losses due to the high density and productivity of crops in this region. However, peak temporal derecho frequency does not directly equate to greater crop losses. Crop areas that experienced reported wind gusts $\geq$ 120 kph were more likely to exhibit condition declines, with the magnitude of degradation generally increasing as crops progressed through vegetative and reproductive stages. Particularly for corn, condition vulnerability was further amplified when severe wind gusts coincided with late-season drought or excessive wetness. Additionally, impacts from derechos were largely governed by pre-derecho crop conditions, which account for stand establishment, canopy vigor, rooting depth, and stresses from moisture, pests, or nutrient deficiencies. Notably, crops in suboptimal condition prior to a derecho were more likely to improve when the storm delivered sufficient precipitation to relieve antecedent stress. These results serve as comprehensive ground-truth information for stakeholders so they may make data-driven decisions for management, preparedness efforts, and targeted intervention.

1. Introduction

Corn (*Zea mays* L.) and soybeans (*Glycine* max L.) are among the most cultivated crops in the United States, with corn accounting for more than 95 % of total feed grain production and soybeans contributing to 90 % of oilseed production (Economic Research Service (ERS), 2025). Consequently, both crops are highly exposed to a variety of weather- and climate-related perils that disrupt growth cycles, reduce productivity, and, ultimately, lead to significant yield declines (e.g., Li et al., 2019; Lindsey et al., 2024; Mourtzinis et al., 2015; Schlenker and Roberts, 2009; Tack and Holt, 2015). Among these perils are derechos, which are long-lived, convectively induced windstorms associated with an extratropical mesoscale convective system (MCS)—including mesoscale convective complexes—that produces severe wind gusts and a damage swath across an extensive area (Corfidi et al., 2016; Hinrichs, 1888; Johns and Hirt, 1987; Squitieri et al., 2023). The societal impacts of derechos are analogous to some landfalling hurricanes and major tornado outbreaks (Ashley and Mote, 2005), and these high-impact windstorms are not confined to the United States; notable events and associated societal impacts have also been documented across Europe (Gatzen et al., 2020), Asia (Xia et al., 2012), Australia (Richter et al., 2014), and South America (Lima de Figueiredo, 2019).

Derechos can result in extensive crop damage and subsequent yield loss, such was the case of the 10 August 2020 Corn Belt derecho that produced over $300 million (2020 USD) in insured corn and soybean indemnity across the region (Risk Management Agency (RMA), 2021). Given the projected increase in the frequency of derechos across key agricultural regions under future climate scenarios (Kaminski et al., 2025), there is a critical need to expand the understanding of how derechos impact corn and soybean conditions and yield. Derechos pose a

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significant risk to crop health and productivity due to the combined effects of severe wind gusts and heavy precipitation. Measured wind gusts within derechos can exceed 200 kph, as observed during the 10 August 2020 Iowa derecho, when measured wind gusts ranged from 177 to 225 kph across a 300 km swath (National Weather Service (NWS), 2020a). Plants exhibit a range of structural and physiological responses to wind stress (Cleugh et al., 1998). For corn, these responses include root lodging, in which the roots fail to properly anchor the plants in the soil, and stalk breakage, which occurs when the stem fractures below the tassel or primary ear (Erndwein et al., 2020). Recovery potential depends strongly on growth stage and type of damage. During the vegetative stage, plants may recover from root lodging through geotropic "goose necking," whereas late-season lodging increases susceptibility to ear diseases, prolongs harvest operations, and reduces grain recovery. Stalk breakage can be further classified by the point of mechanical failure as greensnap, stem buckling, or stalk lodging (Lindsey et al., 2024). Greensnap typically results in complete yield loss for affected plants, while stalk lodging allows for eventual harvest but often slows harvest progress and reduces efficiency, with impacts contingent on the timing of the storm. For soybeans, in addition to root lodging, excessive winds also lead to sandblasting (Armbrust, 1972), leaf defoliation (Saeugling, 2020), and pod shattering (Bayer, 2024) that directly impairs crop quality and yield potential. Additionally, while not a unique feature of derechos, heavy precipitation associated with these storms leading to excess moisture can exacerbate crop losses by damaging root function, restricting nutrient uptake (Parent et al., 2008), and inducing nitrogen deficiencies through leaching and denitrification (Jabloun et al., 2015). Waterlogging further promotes the development of toxic substances, plant diseases, insect infestations, and pathogen outbreaks, compounding crop yield losses (Evans and Fausey, 1999; Li et al., 2019; van der Velde et al., 2012). Though, there are strong environment effects related to soil texture and drainage capacity, as well as management practices such as drainage tiles, which influence whether heavy precipitation results in transient saturation or more prolonged waterlogging. With both excessive wind and precipitation perils considered, to fully understand the overall crop-derecho impacts, two conditions must be considered: 1) derecho characteristics (e.g., magnitude, areal extent) and 2) the characteristics of the target, which includes crop selection, stage of development (Lindsey et al., 2021a; Minami and Ujihara, 1991), hybrid genetics (Bian et al., 2016; So et al., 2013), tillage system (Bian et al., 2016), plant density (Lindsey et al., 2021b), and damage from insects or diseases (Munkvold and White, 2016; Tinsley et al., 2013).

Previous field and modeling studies have examined the effects of strong winds (e.g., Berry et al., 2004; Erndwein et al., 2020; Gramling, 2020; Lindsey et al., 2021a,2021b; Rajkumara, 2008) and excessive precipitation (e.g., Li et al., 2019; Shaw and Meyer, 2015) on cropping systems; but a critical knowledge gap persists in understanding the broader impacts of derechos on crop conditions and yields. Prior studies used Synthetic Aperture Radar (SAR) satellite data to assess corn and soybean damage following derecho events (Hosseini et al., 2020), while others employed the Normalized Difference Vegetation Index (Silleos et al., 2002; Surek and Nador, 2015; Young et al., 2004) and drone imagery (Chauhan et al., 2019; Chu et al., 2017; Hamidisepehr et al., 2020) to evaluate cropland damage from severe thunderstorms on a case-specific basis. Remote sensing products provide high-resolution analyses, yet their effectiveness can be constrained by cloud cover, necessitating cloud-masking techniques. Moreover, remote sensing methods inherently lack in situ validation (Lindsey et al., 2024), limiting their ability to fully capture crop condition dynamics on a weekly basis.

Despite the robustness and completeness of the USDA National Agricultural Statistics Service (NASS) crop condition dataset, crop condition assessments that are published on a weekly basis remain underused in agroclimatological studies. Subjective crop assessments integrate broad agronomic insights, reflecting stand establishment, canopy vigor, rooting depth, and stress from moisture, pests, or nutrient deficiencies. The concept of using "people as sensors" offers a unique advantage in evaluating crop conditions, as human observations can capture crop complexities that agrometeorological models or remote sensing products may not be able to portray completely (Beguería and Maneta, 2020). Additionally, subjective crop condition data have been leveraged to successfully quantify the impacts of tropical cyclones on crop condition ratings and yields in the coastal southern United States, marking a critical step toward a comprehensive assessment of this peril and its broader agricultural implications (Bundy et al., 2023). Therefore, given the projected rise in derecho frequency across key agricultural regions in the United States (Kaminski et al., 2025), a renewed and comprehensive evaluation of their impact on crop conditions and yields is imperative to inform adaptive strategies and resilience planning.

This study investigates the county-level impacts of derechos on corn and soybean crop conditions and yield by employing the nine-year historical record (2015–2023) of USDA NASS gridded crop condition data. The objectives are threefold: 1) quantify changes in crop conditions and modeled yield estimates within derecho footprints; 2) assess the effects of these changes based on factors such as phenological stage, wind and precipitation magnitude, location, and precursor conditions; and 3) examine how derechos affect crop recovery through the growing season. Stakeholders involved in agricultural production, risk management, and policy development can use these results to better anticipate and prepare for the potential impacts of derechos on crop conditions and yield. Results herein can also be used to help stakeholders make data-driven decisions on crop selection, insurance coverage, and resource allocation. Furthermore, agricultural extension agents or local agricultural advisors can leverage this information to provide targeted recommendations to farmers in regions more prone to derechos. Although this research focuses on crop impacts in the United States, the methods and findings provide a transferable framework for assessing vulnerability to derechos in other global agricultural regions. Ultimately, this study presents valuable, novel information to a wide range of stakeholders, helping to enhance the resilience of agricultural systems against extreme weather events.

2. Data and methods

2.1. Derecho footprints

2.1.1. MCS identification and tracking

MCSs were identified and tracked in 15 min, 1 km NEXRAD base reflectivity mosaics—specifically, the N0R base reflectivity product from Iowa State University's Iowa Environmental Mesonet (IEM; IEM, 2024), which provides a continuous and relatively consistent record from 1995 to present and has been previously used to assess the United States derecho climatology (Squitieri et al., 2025a,2025b). The methods outlined in Haberlie & Ashley (2018a,2018b) and subsequently applied in other work examining MCSs (Ashley et al., 2019; Haberlie and Ashley, 2019a, 2019b; Haberlie et al., 2023,2024; Kaminski et al., 2025; Wallace et al., 2025) were used herein. This approach employs segmentation to create MCS slices (Haberlie and Ashley, 2018a), and tracking to concatenate slices into swaths (Haberlie and Ashley, 2018b) based on the criteria of an MCS: 1) an organized thunderstorm complex which contains deep convection needs to be present; 2) exhibits a major axis over 100 km; and 3) persists for at least three hours (Parker and Johnson, 2000). Ultimately, the distribution of mean MCS track counts during the warm season over the 2015–2023 period aligned with previously established patterns of warm-season MCS activity (Haberlie and Ashley, 2019a), confirming the use of historical MCS tracks to detect derechos.

2.1.2. NOAA severe storms database

Severe convective wind report data from the National Oceanic and Atmospheric Administration (NOAA) severe storms database (SVRGIS; NOAA, 2024) were collected over the 2015–2023 period and leveraged in identifying derecho events. The SVRGIS database is one of the most complete and readily available (Tippett et al., 2015), but several non-meteorological factors may create spatiotemporal biases (Allen and Tippett, 2015). These biases associated with wind reports include a large increase in the number of reports over time, clustering in populated areas and underreporting in rural regions, inconsistencies in estimated wind gusts, the potential for inaccurate reporting, and the tendency for lower-end wind events to go unreported (Agdas et al., 2012; Doswell et al., 2005; Edwards et al., 2018; Johns and Evans, 2000; Trapp et al., 2006; Weiss et al., 2002). However, the severe wind report record is much more homogenous from 2015 onward (Gensini et al., 2020). No adjustments or corrections were applied to the wind report data; rather, the attribution of this dataset to MCS tracking output and the selection of derecho criteria were conducted considering these limitations. Additionally, for the crop condition analysis, severe convective wind reports were used to isolate counties within a derecho footprint that experienced a measured or estimated wind gusts $\geq$120 kph, which can be exceptionally damaging to crops (Cleugh et al., 1998). Some of the limitations in using severe wind gust data for this portion of the analysis were minimized as only the maximum recorded wind gust was retained in counties that had more than one severe convective wind report.

2.1.3. *Derecho criteria*

Since there are several ways damaging wind gusts can occur within a derecho—sometimes preceding or following the main convective line—and given the known issues with severe wind reports, the use of a spatiotemporal buffer was essential to accurately attribute severe convective wind reports to the MCS tracking output. Three buffers were tested on all tracking output, with close examination of performance for several known derecho events, such as the 10 August 2020 Corn Belt derecho. At each 15 min MCS slice within a given swath, wind reports were assigned if they were within 20 km and $\pm$7.5 min (Ashley et al., 2019), within 30 km and $\pm$15 min, and within 40 km and $\pm$30 min (Squitieri et al., 2025b). To avoid assigning the same report to more than one MCS slice, reports were assigned to the first slice for which they are a match and then removed from consideration. Although all three buffers adequately captured most wind reports associated with a given MCS, the 40 km/$\pm$30 min buffer using base reflectivity as opposed to composite reflectivity (Ashley et al., 2019), was adopted as it provided the most comprehensive coverage. MCS swaths and their associated wind reports were assessed against derecho criteria (Ashley and Mote, 2005; Johns and Hirt, 1987; Bentley and Mote; 1998), and this study followed the low-end derecho criteria (Coniglio and Stensrud, 2004):

- There must be a concentrated area of convectively induced wind damage or wind gusts greater than 93.6 kph that has a major axis length of 400 km or more.
- The wind reports must exhibit a nonrandom pattern of occurrence, either as a singular swath or as a series of swaths, with chronological progression.
- No more than 3 h and 200 km separating successive wind reports (i.e., the associated MCS must have temporal and spatial continuity).
- Multiple swaths of damage must be part of the same MCS as indicated by examining available base reflectivity radar data.

Hurricane-force wind gusts (Coniglio and Stensrud, 2004; Johns and Hirt, 1987; Squitieri et al., 2025b) and a major axis length larger than 400 km (Corfidi et al., 2016; Storm Prediction Center (SPC), 2024) were not required to meet the low-end derecho criteria. Previous studies examining derechos have modified the Johns and Hirt (1987) criteria to suit the underlying data and period examined (Squitieri et al., 2023), with recent work proposing stricter criteria to define derechos as long-lived, progressive, cold pool-driven events (Corfidi et al., 2016; Squitieri et al., 2025b). Due to ongoing derecho-definition debates and the noted biases in the SVRGIS database, the low-end derecho criteria were applied to the severe wind reports associated with the MCS tracking output, and all wind swaths and radar imagery associated with low-end MCS events were manually examined. For example, in the case of 10 August 2020, an MCS was apparent across much of Iowa, Illinois, and Indiana (Fig. 1a). With the use of MCS-tracking methods, severe convective wind reports, and low-end derecho criteria, a derecho footprint was generated for the event, with extensive coverage across much of the Corn Belt (Fig. 1b).

Of the 223 MCSs that produced low-end derecho wind swaths during the warm season (May–August) over the 2015–2023 period, 79 events were retained for analysis, with many eliminated for not meeting the nonrandom pattern of occurrence criteria. The warm season was used as opposed to the entire growing season (May–October) because there were only three derechos during September and October across the nine-year record. Nearly 80 % of retained events produced the necessary number of hurricane-force wind gusts, or greater, to meet moderate or even high-end derecho classifications (Coniglio and Stensrud, 2004). The mean number of derechos per warm season (9) was slightly lower than previous assessments of the United States derecho climatology (Kaminski et al., 2025; Li et al., 2025), with some events missed due to known cell tracking issues (Haberlie and Ashley, 2018b). However, this lower number of events may be attributed to the limited study period. For example, the 6 June 2020 Rocky Mountain-Northern Plains derecho (NWS, 2020b) did not meet the major axis requirement because the tracking failed to capture the parent MCS until northwestern Wyoming, hindered by radar challenges in mountainous terrain. Manually identifying missed events is challenging without a publicly available and standardized derecho database. However, since the focus of this study was on assessing the impact derechos imposed on crop conditions and yield rather than constructing a derecho climatology, the sample size was sufficient for a robust evaluation. While a few events may be missed, the established methods ensure a comprehensive and reliable assessment of derecho impacts on agriculture.

2.2. *USDA crop condition ratings*

2.2.1. *Crop condition data background*

The USDA invests millions of dollars annually—using extension agents and Farm Service Agency staff who contain expert crop knowledge—to collect, process, and disseminate data in their weekly Crop Progress and Condition Report (CPCR). The CPCR is widely used by farmers, agribusiness, commodity traders, government agencies, and research institutions (Beguería and Maneta, 2020; Lehecka, 2014), making it the most requested publication distributed by NASS (Lehecka, 2014). Issued at 4:00 PM Eastern Standard Time on the first business day of the week from April through November, the CPCR provides essential information about farmer activities such as planting and harvesting progress, progress of crops through various phenological stages of development, and the focus of this study—general crop condition ratings. This elaborate network of crop reporters consists of approximately 3600 respondents, with at least one or two for each county, covering over 75 % of crop production across the United States (USDA, 2025). Surveyors are asked to report subjective estimates of crop progress and conditions based on standard USDA definitions for the entire week ending on Sunday (USDA, 2025). For the crop condition portion of the survey, surveyors are asked to estimate the percentage of the evaluated crop that is in excellent, good, fair, poor, and very poor condition. Standard definitions for these condition categories are as follows (USDA, 2016):

- *Excellent*: Yield prospects are above normal. Crops are experiencing little or no stress. Disease, insect damage, and weed pressures are insignificant.
- *Good*: Yield prospects are normal. Moisture levels are adequate, and disease, insect damage, and weed pressures are minor.
- *Fair*: Less-than-normal crop condition. Yield loss is a possibility, but the extent is unknown.

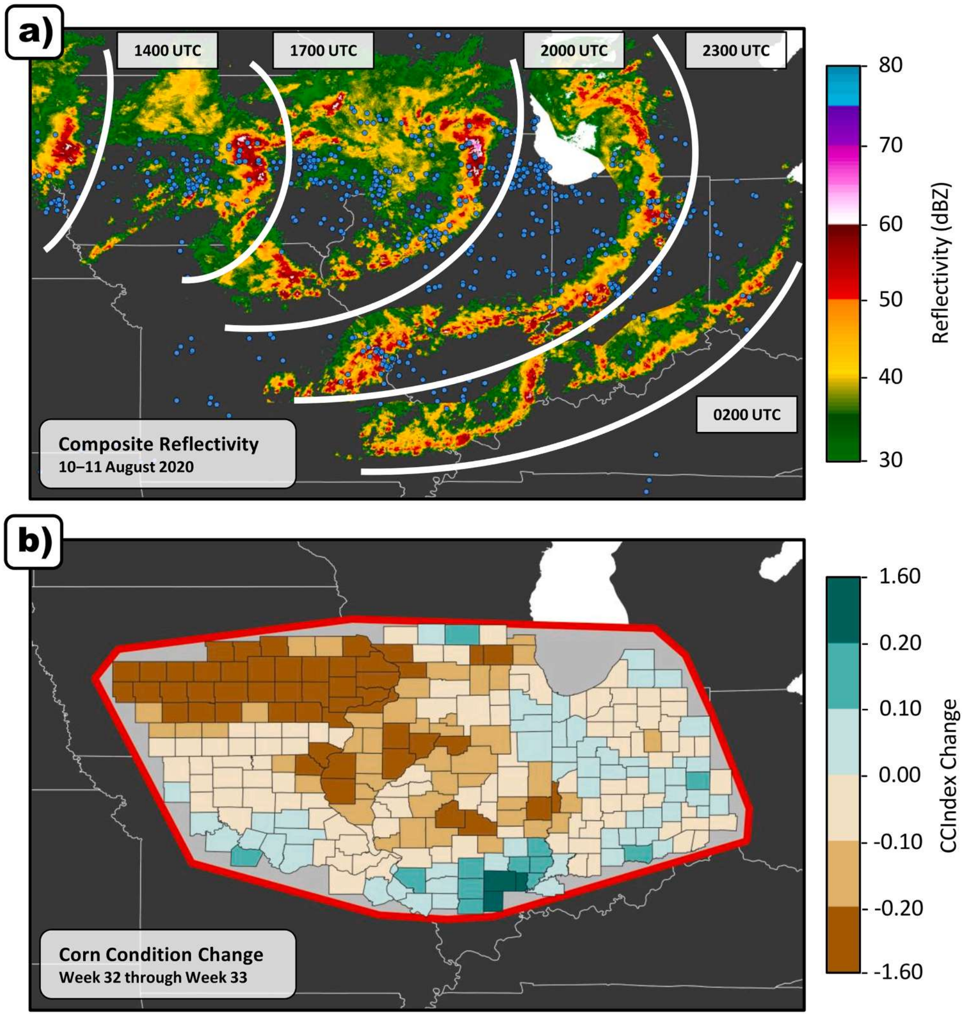

Fig. 1. Example case from the 10 August 2020 Corn Belt derecho. a) Composite reflectivity (masked for ≥30 dBZ) at three-hour interval timestamps. White lines denote the leading edge of the storm that separate the timestamps. Wind reports from SVRGIS are overlayed in blue. b) County-level crop condition index (CCIndex; explained in Section 2.2.2) deltas between week 32 (week before the derecho; week 0) and week 33 (week of the derecho; Week 1). The counties included are completely within the derecho footprint (red outline).

- *Poor*: Heavy degree of loss to yield potential, which can be caused by excess soil moisture, drought, disease, etc.
- *Very Poor*: Extreme degree of loss to yield potential; complete or near crop failure.

For quality control measures, each datapoint is reviewed by NASS for reasonableness and consistency by comparing it with prior weeks' data, historical averages, and reports from adjacent counties. USDA Field Offices aggregate these quality-controlled data to the state level by weighting each county's reported data by NASS county acreage estimates (USDA, 2025). State estimates are submitted to the Agricultural Statistics Board, compared with adjacent states, and aggregated to the national level by weighting each state's conditions by the state's three-year planted acreage estimates for the given crop (USDA, 2025). Additionally, weather events and respondent comments are considered in the condition estimation, and conditions are subject to revision the following week (USDA, 2025).

Crop condition data from the CPCR are used on a weekly basis to 1) forecast crop yields at the state and national level (Beguería and Maneta, 2020; Bundy and Gensini, 2022; Bundy et al., 2024, 2025; Irwin and Good, 2017a,2017b; Irwin and Hubbs, 2018b); 2) quantify impacts on agricultural future markets (Bain and Fortenbery, 2013; Fernandez-Perez et al., 2018; Isengildina-Massa et al., 2016; Karali, 2012; Karali et al., 2016; Lehecka, 2013, 2014; Lehecka et al., 2014; McKenzie and Ke, 2022); and, more recently, 3) quantify crop condition changes under extreme weather perils (Bundy et al., 2023). However, previous assessments using crop condition data were limited to the state and national level, an inherent limitation of the CPCR tabular data. The aggregation of the raw crop reports to the state and national level results in the loss of detailed information about conditions and spatiotemporal patterns at the county level (Rosales, 2021). Aggregation to state and national levels is done, in part, to protect the confidentiality of farmers whose operations may cover much of the production in a county (Rosales, 2021). However, in response to the increasing demand for higher-resolution crop condition data, NASS generated a geospatially referenced, gridded dataset that represents the raw crop report data while still protecting farmer confidentiality (Rosales, 2021).

2.2.2. Gridded crop condition data

Gridded crop condition layers are curated by NASS using the raw reports within each county. For the gridded condition dataset, the original percentage-in-category variables are reinterpreted into a single numerical index—the Crop Condition Index (CCIndex)—for each crop and week (Rosales, 2021; Eq. (1)):

$$CCIndex = (5 * \%Excellent + 4 * \%Good + 3 * \%Fair + 2 * \%Poor + \%VeryPoor)/100 \tag{1}$$

The CCIndex ranges from 1 to 5, with an index rating of 5 corresponding to 100 % of the surveyed crop reported in excellent condition and an index rating of 1 corresponding to 100 % of the crop reported in very poor condition.

NASS generates weekly 9 km gridded CCIndex data by initially mapping raw condition reports onto crop-specific land cover polygons derived from the NASS Cropland Data Layers (Rosales, 2021). Random points corresponding to the county acreage of the crop are created within these polygons, even for counties with minimal cropland. Kriging spatial interpolation predicts crop condition values for all locations, followed by a focal statistics filter to obscure original data points. The smoothed gridded values are averaged within local neighborhoods to reduce outliers, and the final dataset is masked to include only states with reported data, resulting in 9 km resolution gridded crop conditions (Rosales, 2021). Historical gridded crop condition data are available from April through November dating to the 2015 growing season for corn, cotton, soybeans, and wheat (USDA, 2024). More details on the gridded data curation are available in Rosales (2021).

When gridded CCIndex data were aggregated to the county level, crop condition ratings were a statistically significant covariate of yield during the critical reproduction period through harvest for 90 % of corn and soybean-producing counties in the United States (Bundy et al., 2025c). Furthermore, at least 50 % of the variance in yield was explained by the CCIndex for over 70 % of corn- and soybean-producing counties during the 2015–2023 period. Additionally, when gridded crop condition data were aggregated to the state level, there were no statistically significant differences between the grid-to-county-to-state data and the tabular CPCR condition data (Bundy et al., 2025c). This quantified relationship between NASS gridded crop condition data, yield, and CPCR data substantiates the utility and fidelity of this dataset, supporting its practical application in research (Bundy et al., 2025c). Therefore, this study used the weekly county-level corn and soybean CCIndex data over the 2015–2023 period to quantify the impacts of derechos on crop conditions and yield. County-level crop conditions were masked using the derecho footprint, with only counties entirely contained within the footprint included in the analysis. A limitation to using the subjective USDA crop conditions is that areas that were impacted by a derecho may not have been surveyed. However, if a known weather event occurred during the surveyed week and affected a specific location, efforts were made to prioritize and closely examine the impacted areas (USDA, 2025). Also, other weather events may occur during the week in addition to a derecho, which may impact the trajectory of condition ratings.

2.3. Additional supporting datasets

2.3.1. USDA crop yield data

In addition to providing information on crop condition estimates, NASS provides county-level yield data for a multitude of crops through the QuickStats database (NASS, 2025). Corn and soybean yield data were collected for each county within the 1990–2023 period. To account for long-term trends in yield data, a detrending procedure was applied, ensuring a fair comparison across all crop-county combinations. Each crop-county combination must have at least 20 years of available yield data in the 1990–2023 period and have at least eight of the nine years with yield data in the 2015–2023 period to be included in this analysis. To detrend the yield data, a linear regression adjustment equation (Eq. (2)) was used for each crop-county combination (Bundy and Gensini, 2022; Bundy et al., 2024, 2025c; Irwin and Good, 2017a):

$$Y_{adj} = Y + [1(x_i - x_n)] \tag{2}$$

where Y is the respective year's crop yield, β_1 is the rate of change in the 34-year yield data, x_i is the total number of years used, and x_n is the year number. While limited to only nine years of county-level crop condition data (2015–2023), coefficient of determination values along with the regression p-values were still computed between the CCIndex and detrended crop yields at the weekly level for each county. Only counties with a statistically significant (95 % significance level; p-value < 0.05) coefficient of determination between crop conditions and yield were used for the yield portion of the analysis.

2.3.2. PRISM precipitation data

Daily precipitation totals from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; Daly et al., 1994) were collected for the 2015–2023 period (PRISM, 2024). This observationally driven dataset is provided on a ~4 km grid and consists of interpolated and bias-adjusted values derived from multiple high-quality data sources. Daily PRISM data were spatially aggregated to the county level by calculating the mean of all intersecting grid cells within each county. Only daily precipitation totals directly attributed to the derecho were retained, and the analysis was restricted to counties located within the derecho swath. Further, counties with precipitation totals $\geq$ 50 mm within a derecho footprint were isolated to analyze the effects of heavy precipitation on crop condition and yield changes. A threshold of $\geq$ 50 mm was selected, as this exceeds two standard deviations above the normal for daily precipitation totals for most counties during the summer growing season—considered extremely wet (Li et al., 2019).

2.3.3. Palmer drought severity index data

Weekly Gridded Palmer Drought Severity Index (PDSI; Rhee and Carbone, 2007) were collected for the 2015–2023 period (THREDDS, 2024). Gridded PDSI data (~4 km horizontal grid spacing) employs a modified version of the Palmer formula, which uses reference evapotranspiration and precipitation from gridMET and a static soil water holding capacity layer (top 1500 mm) from the USDA STATSGO soils dataset (Rhee and Carbone, 2007). More details on the methods behind the gridded PDSI are available in Rhee and Carbone (2007). The PDSI is a standardized index based on a simplified soil water balance and estimates relative soil moisture conditions. Weekly PDSI data were spatially aggregated to the county level by calculating the mean of all intersecting grid cells within each county. Only counties with a PDSI during the week prior to the derecho were retained, and only the counties directly attributed to the derecho were used. Further, counties within the derecho footprint with a PDSI of $\geq$ 3.0 (severe wetness) or ≤ -3.0 (severe dryness) were isolated to analyze the precursor effects of soil moisture on crop condition and yield changes proceeding a derecho.

2.4. Methods

Methods of this study follow Bundy et al. (2023), which investigated the impacts of tropical cyclones on crop conditions and yield in the coastal southern United States. For each derecho, crop condition (CCIndex) data were analyzed for four key time periods: the calendar week preceding the storm (referred to as Week 0), the week of the storm (Week 1), the week following the storm (Week 2), and the final reported week of crop conditions during the growing season (Final Week). Changes in CCIndex ratings were quantified using three metrics: 1) Week 1 minus Week 0, capturing the immediate impact of the derecho (example of the 10 August 2020 in Fig. 1b); 2) Week 2 minus Week 0, reflecting short-term recovery or further decline, which is recommended in lodging evaluation (Lindsey et al., 2024); and 3) Final Week minus the mean between Week 1 and Week 2 conditions, assessing longer-term crop condition trends through the growing season. County-level CCIndex deltas were computed for the corresponding yield, except yield impacts were measured as percent change. For each county, the change in condition and yield represented a singular datapoint. Therefore, each derecho contained multiple datapoints depending on how many corn- and soybean-producing counties were within the derecho footprint.

To examine differences in condition and yield changes between each month, a combination of three assessments were made: 1) computing how many datapoints resulted in a decrease or increase in CCIndex and yield; 2) examining the mean and interquartile distribution of box and whisker plots for each month; and 3) assessing the statistically significant differences in CCIndex and yield changes for each month using the Mann-Whitney *U* test at the 95 % significance level (p-value < 0.05). These assessments were completed for each month for all counties within a derecho footprint; all counties within a derecho footprint with a reported wind gust $\geq$ 120 kph; all counties within a derecho footprint with daily precipitation totals $\geq$ 50 mm; all counties within each footprint with a PDSI of $\geq$3.0 or ≤ -3.0; and for all counties with a precursor CCIndex rating (Week 0 CCIndex rating) of $\geq$ 4.0 or $\leq$ 3.0.

3. Results and discussion

3.1. Derecho risk and crop exposure

3.1.1. Spatial risk

Of the 79 warm season (May–August) derechos that were identified across the central and eastern United States during the nine-year study period (2015–2023), each storm impacted at least one corn- or soybean-producing county. The highest frequency of derechos was spatially concentrated within the Corn Belt and the eastern portion of the Great Plains (Fig. 2a), similar to the warm-season derecho frequency found in prior derecho climatologies (Ashley and Mote, 2005; Coniglio and Stensrud, 2004; Guastini and Bosart, 2016). Both regions are characterized by a high-density of corn (Fig. 2b) and soybean (Fig. 2c) production, with the top five producing states contributing to 60 % and 53 % of national corn and soybean production, respectively (NASS, 2025). During each warm season, around one-third of the national corn and soybean production was affected by at least one derecho, translating to over 11 million corn and soybean ha impacted. This exposure equated to an estimated $20 billion USD in corn production and $15 billion USD in soybean production at risk for damage each year over the May–August period (NASS, 2025). On a per-storm basis, derechos impacted a mean of 1.5 million ha of corn and soybeans (4.3 % of national production), with study-period maximum exposure reaching 9.3 million corn and 8.7 million soybean ha, and a minimum exposure of 4630 corn and 8850 soybean ha. Over all nine years, nearly 90 % of national corn and soybean acreage experienced at least one derecho. Counties that recorded nine or more derechos over the study period contained a mean yield of 11,460 kg ha^{-1} for corn and 3500 kg ha^{-1} for soybeans, both yields in the upper 75th national percentile. In contrast, lower-yielding counties—-those producing less than 9500 kg ha^{-1} for corn and 2200 kg ha^{-1} for soybeans (lower 25th percentile)—experienced a mean of three derechos over the 2015–2023 period.

The juxtaposition between high corn and soybean exposure and the highest climatological derecho risk resulted in the most severe derecho impacts to be distributed across the Corn Belt. Of the 79 derechos, the 10 August 2020 derecho was the most detrimental for both corn and soybean production over the 2015–2023 period, inflicting widespread damage across the Corn Belt (Fig. 1; Hosseini et al., 2020). Story County, Iowa, bore the brunt of the damage, experiencing a maximum CCIndex decline of 1.23 proceeding the derecho, with 71000 ha impacted (Hosseini et al., 2020). Meanwhile, Monroe County, Illinois, recorded the sharpest soybean CCIndex change at -1.24 following the 10 August 2020 derecho. Beyond crop conditions, yield losses were equally severe, as Cedar County, Iowa experienced the largest yield change of -22 % for corn and -7 % for soybeans. Other major derecho events—i.e., 17 June 2022 derecho in the Corn Belt/Appalachian region and the 29 June 2023 derecho in the southern Corn Belt—caused significant damage to crop conditions and subsequent yields, with county-level CCIndex declines of at least 1.00 and yield reductions of at least 10 %. The broader impact of these events was evident when considering changes over the entire study period, where county-level corn and soybean CCIndex declines were as low as -1.36, with yield declines as severe as 37 % following a derecho. Notably, the most severe declines in weekly corn and soybean conditions, in both the historical gridded crop condition record (dating to 2015) and among the state-level condition record (dating to 1986), were comparable to the crop condition and yield impacts from hurricanes (Bundy et al., 2023).

Among the states within the USDA-defined Corn Belt (Missouri, Illinois, Indiana, Iowa, and Ohio), 35 % of corn-producing and 30 % of soybean-producing counties experienced a maximum CCIndex rating decline of at least 0.20 (Figs. 3a and 3b). Between 2015 and 2023, Illinois experienced the most negative derecho impacts on corn and soybeans, with a maximum CCIndex decline county-mean of 0.33, followed by Iowa (-0.24), Kentucky (-0.19), Nebraska (-0.15), and Missouri (-0.15). With an 82 % explanatory power between CCIndex changes and yield changes (mean CCIndex change of 0.05 generally corresponds to a 1 % change in yield), the Corn Belt also experienced the most pronounced negative yield changes from derechos over the nine-year study period (Fig. 3c, and d). Once again, Illinois was the most affected state, with a county-mean yield change of -6.1 %, followed by Nebraska (-5.1 %), Missouri (-4.7 %), Kansas (-4.3 %), and Iowa (-3.8 %). Between conditions and yield, the impacts across the Corn Belt were 3x more severe than elsewhere. This observed pattern across the Corn Belt aligns with previous research linking higher crop exposure to increased vulnerability to wind (Lindsey et al., 2021b) and excessive

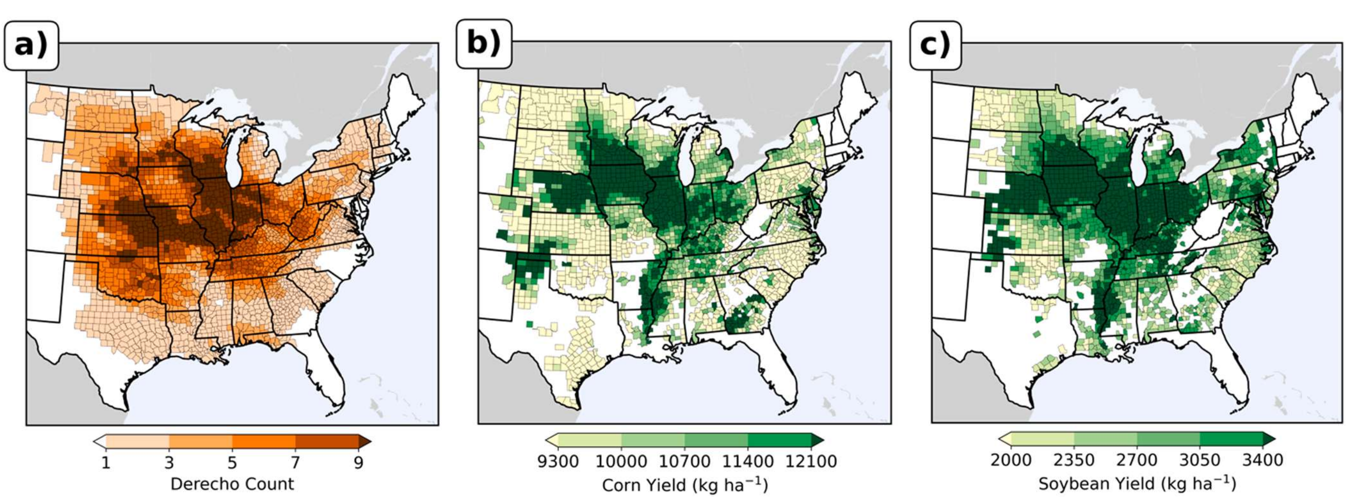

Fig. 2. Study period (2015–2023) a) total derecho count by county, b) mean corn yield, and c) mean soybean yield by county over the nine-year epoch.

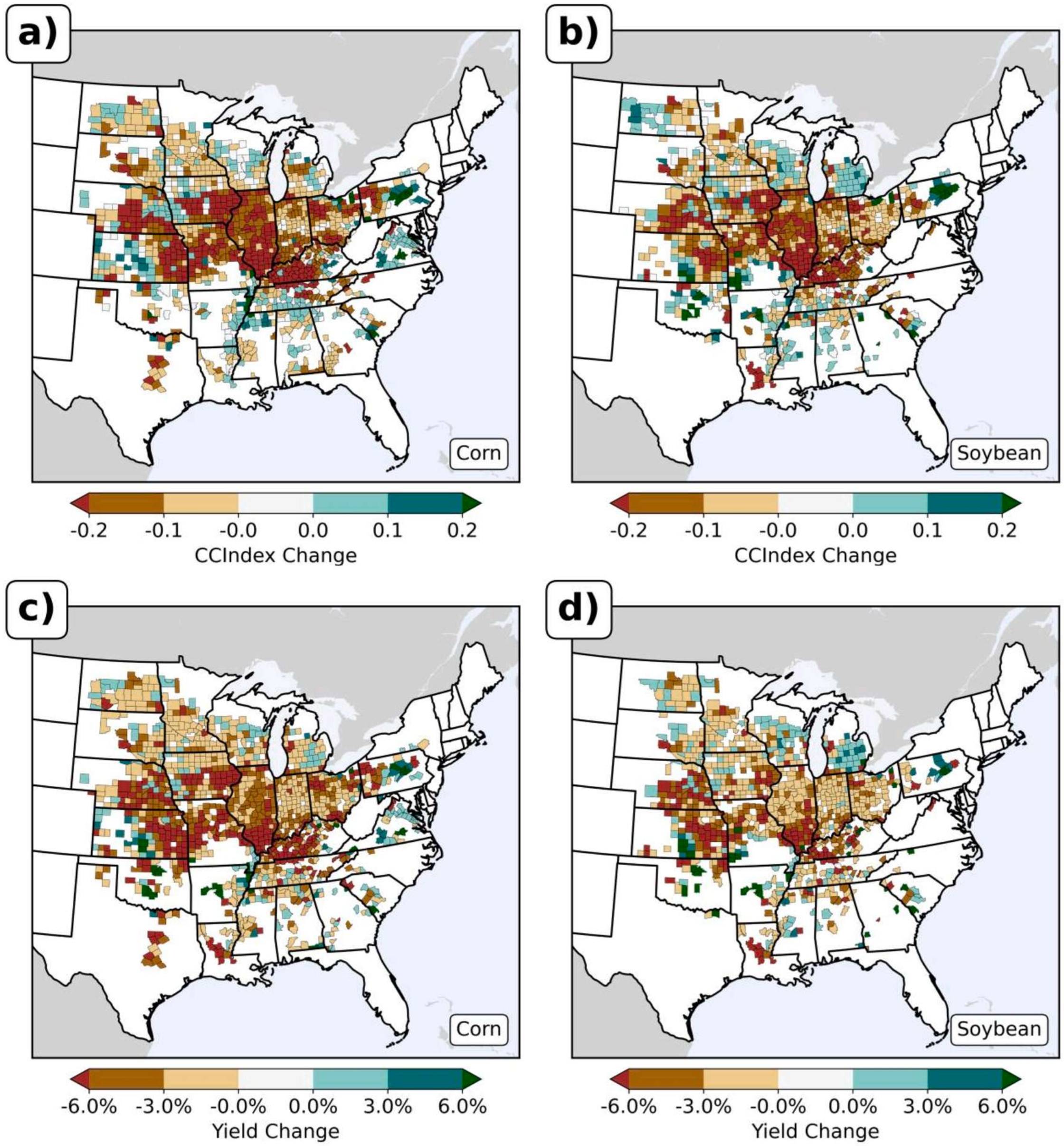

Fig. 3. Most severe CCIndex negative delta when considering every 2015–2023 derecho for a) corn and b) soybeans and the corresponding modeled yield changes for c) corn and d) soybeans.

precipitation impacts (Li et al., 2019). For instance, an Ohio corn field study demonstrated that increasing plant density from 59000 to 124000 plants ha^{-1} increases root lodging—a 1.4 % increase in incidence per additional 2470 plants ha^{-1} (Lindsey et al., 2021b). Empirical evidence further suggests that states with larger agricultural production suffer disproportionately from climate extremes compared to smaller-producing states, which is attributed to the larger harvested area and higher plant density (i.e., more targets) in major producing states (Li et al., 2019; Lobell et al., 2014). In addition to increasing the number of plants exposed to derechos, higher planting densities induce physiological shade avoidance responses—such as taller growth, thinner stalks, and reduced root systems—that further heighten lodging susceptibility (Sher et al., 2018). Therefore, variation in lodging and other stressors is not solely a function of the number of plants within the storm footprint but also reflects physiological changes that amplifies damage vulnerability.

Every derecho in the study period caused at least one corn- and soybean-producing county to be negatively impacted from both a condition and yield standpoint. Overall, 75 % of corn- and soybean-producing counties affected by a derecho experienced a decline in crop conditions over the 2015–2023 period, translating to 80 % of national corn and soybean production. Consequently, only a small number of counties exhibited a net benefit following a derecho, and these select counties were mostly within minor-producing regions outside the Corn Belt, including parts of Michigan, Pennsylvania, and Louisiana. This spatial pattern highlights the critical interplay between crop exposure and derecho risk, reflecting an agricultural form of the Expanding Bull's-Eye Effect—a concept originally developed through examining human and built-environment exposure with weather hazards (Ashley and Gilson, 2009; Ashley and Strader, 2016; Ashley et al., 2014; Bouwer, 2011, 2013; Changnon, 2009; Changnon et al., 1997, 2000; Doswell et al., 1999; Hall and Ashley, 2008; Janković and Schultz, 2017; Mechler and Bouwer, 2015; Paulikas and Ashley, 2011; Rosencrants and Ashley, 2015; Strader et al., 2017a, 2017b, 2018,2024). In an agricultural context, disaster potential (i.e., significant crop yield loss) is not solely dictated by the total area of croplands but rather by the spatial distribution of croplands across the risk landscape. While total crop area in the Corn Belt remained relatively stable over the study period—unlike the clear expansion observed for human and property exposures—the climatological corridor of peak derecho frequency overlaps directly with the region's highest-yielding corn and soybean production. This spatiotemporal alignment reflects a bull's-eye effect, as not only is there a higher climatological probability of derechos in the Corn Belt, but these storms occur where crop density and yield potential are the greatest. In effect, the concentration of "targets" (i.e., crops) in the most productive counties elevates the likelihood that derechos will translate into severe and potentially widespread agricultural impacts. In peripheral production areas, improvements in conditions and yield prospects reflect a unique interplay of lower planting densities and varietal adaptation, making crops more responsive to precipitation relief and, in some cases, less susceptible to wind damage. Moreover, winds typically weaken along the margins of the derecho footprint, yet these areas often still receive abundant precipitation, lowering the risk of wind-induced damage while enhancing the potential for crop condition improvements. Understanding this interplay requires a holistic view of risk—the likelihood of a weather or climate-related hazard occurring in both space and time—alongside exposure and the vulnerability of the affected agricultural system. These interconnected factors are fundamental in assessing the probability and severity of crop losses due to extreme weather events.

3.1.2. Temporal risk

Temporally, the highest derecho frequency was observed in June, with 30 occurrences over the nine-year period, followed by July (25), May (20), and August (8) (Fig. 4). Although limited to a nine-year dataset, this short-term climatology aligns reasonably well with previous, longer-term derecho climatologies—indicating peak derecho activity in June and July (Ashley and Mote, 2005; Coniglio and Stensrud, 2004; Guastini and Bosart, 2016). While derechos follow a distinct seasonal pattern, the extent of agricultural damage depends not only on storm frequency but also on the vulnerability of crops at various phenological stages (Lindsey et al., 2024). In May, corn and soybean planting are in full progress, with emergence actively underway across key production regions (Fig. 4). Peak derecho frequency in June coincides with critical vegetative stages for both corn and soybeans, as by the end of the month, based on a five-year average of phenology, over 93 % of both crops had fully emerged and are more susceptible to weather extremes. Like June, July also experienced a mean of three derechos per year, which marks the peak reproductive stage for corn (silking) and the near peak of pod setting for soybeans. In contrast, August experienced a markedly lower derecho frequency, thereby reducing the climatological risk to crops—a period when the bulk of grain filling and starch accumulation occurs in corn and when soybeans reach peak pod setting. However, a lower climatological derecho frequency does not necessarily equate to reduced crop loss vulnerability, as condition declines and yield loss is influenced by crop phenological stage, storm magnitude, and precursor conditions—relationships that will be explored in greater detail in subsequent sections.

3.2. Contributing factors to crop-derecho impacts

During the warm season from 2015 through 2023, the mean county-level CCIndex change within derecho storm footprints was –0.01 in Week 1 and Week 2, corresponding to a mean yield change of around −0.5 % for both corn and soybeans. Additionally, a total of 48 % of counties experienced a decline in crop conditions and yield in Week 1, while 46 % exhibited a decline in Week 2. Even in some of the most impactful derechos to corn and soybeans (e.g., 10 August 2020, 17 June 2022, 29 June 2023) during the study period, there was still variation in crop responses, as while many counties experienced subsequent yield losses, others improved in condition and yield potential (Supplemental Table 1). Previous research has demonstrated hybrid variability within damaging wind swaths can result in divergent yield outcomes, as demonstrated by the 10 August 2020 derecho (Barten et al., 2022). The near-equal probability of crop condition deterioration at the county level highlights the need for a comprehensive examination of factors, both independently and in combination, to better understand the mechanisms influencing crop vulnerability to derechos.

3.2.1. Phenological stage timing

Derechos caused declines in conditions and yield prospects across both corn- and soybean-producing counties during all warm-season months, indicating that crop vulnerability persists across all phenological stages, albeit to varying degrees (Fig. 5). From May through August, spanning the period from crop emergence to the onset of maturity for both corn and soybeans, a general declining trend in CCIndex deltas and yield changes (from early improvements to negative changes later) was observed. While early-season improvements gradually transitioned to declines later in the warm season, mean changes for both crops were statistically insignificant. In May, as corn and soybeans emerge and

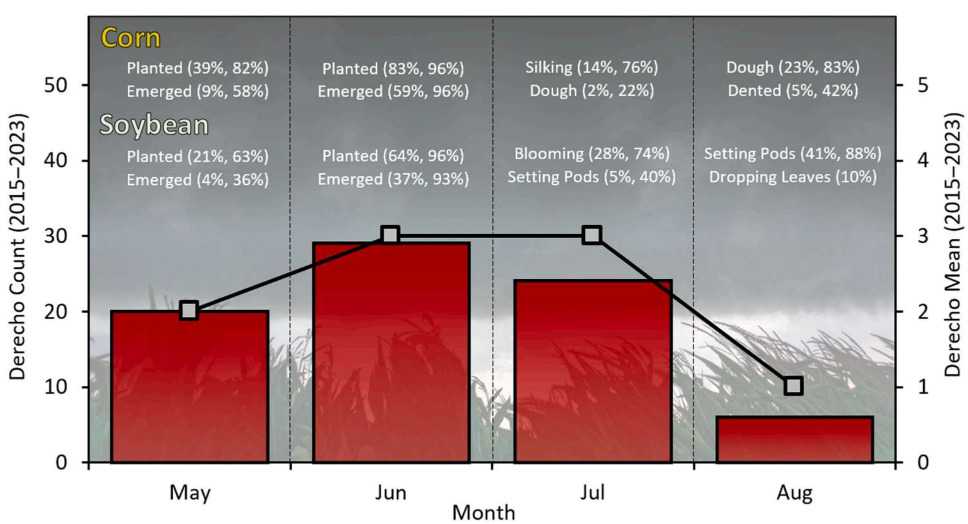

Fig. 4. (left axis) Number of U.S. derechos during the study period (2015–2023) by month; (right axis) mean number of derechos by month over the nine-year period. For corn and soybeans, the five-year phenological progress means are within each month (first number is the mean during the first date of the month, second number is the mean for the last available date of month).

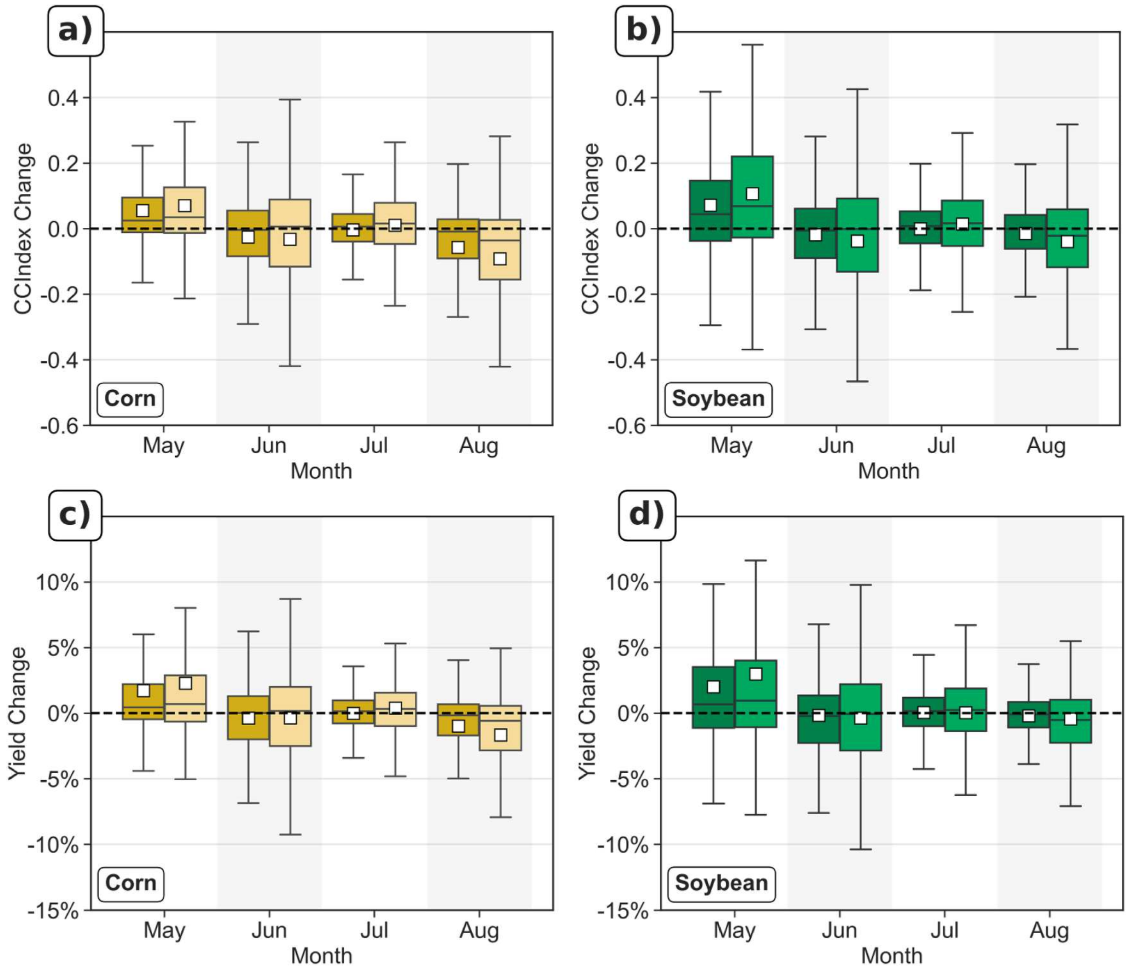

Fig. 5. Box and whisker plots of all week 1 (darker shade) and week 2 (lighter shade) CCIndex deltas from week 0 for each derecho that impacted a) corn counties and b) soybean counties. Modeled yield deltas (measured as percent change) of all week 1 and week 2 derecho impacts are represented by month for c) corn and d) soybeans. Each box and whisker present a six number summary: whiskers represent the 1.5 multiple of the interquartile range (outliers considered but not included in plots); boxes represent first quartile (25th percentile) and third quartile (75th percentile) values; black line horizontal within boxes represent the median value; white squares represent the mean value.

enter their early vegetative stages, both crops exhibited condition and yield improvements, with CCIndex rating changes increasing by 0.10–0.15 and mean yield increases, ranging from 2 % to 4 % (Fig. 5). In total, 71 % of corn-producing counties improved in conditions and yield, while 67 % of soybean-producing counties improved during May. Overall, early-season resilience to derechos is largely due to rapid vegetative growth, which allows for leaf regrowth and structural recovery if damage is not severe (Gardiner et al., 2016). Additionally, the growing point for corn remains below ground and up to about the V5 stage, providing protection from above ground injury. Soybeans possess axillary buds capable of regenerating leaves and branches following defoliation, which supports recovery during the vegetative stages of development.

By June, as corn and soybeans advance through their vegetative growth stages, declines in crop conditions and yield became pronounced (Fig. 5). During this phase, both crops undergo rapid biomass accumulation, canopy expansion, and root system development. As a result, crops in June are increasingly vulnerable to derechos and other adverse weather events, as damage during vegetative stages can have lasting impacts on plant health by delaying development and reducing yield potential later in the season (Bundy et al., 2025c; Irwin and Good, 2017a). Following a derecho, mean CCIndex changes ranged from −0.04 to −0.07 during June, with a mean yield change ranging from 0.0 % to −1.1 % for corn and soybean-producing counties within a derecho footprint. In contrast to May, a total of 51 % of corn-producing counties and 54 % of soybean-producing counties declined in conditions and yield when considering all 30 June derechos during the nine-year study period.

July is a critical period for corn and soybean development, as both crops enter key reproductive stages that significantly influence final condition and yield anomalies (Bundy and Gensini, 2022; Bundy et al., 2024; Westcott and Jewison, 2013). Corn begins with silking, followed by pollination and kernel set in July (Bayer, 2020), while soybeans typically initiate their reproductive phase toward the end of July, marked by the onset of flowering and early pod formation (Nleya et al., 2019). During July, crop conditions accounted for 86 % of the variance in corn and 62 % of soybean yield anomalies at the national level (Bundy et al., 2024). Changes in crop conditions and yield following a derecho in July exhibited a relatively balanced distribution between counties experiencing improvements and those facing declines (Fig. 5). Mean CCIndex changes ranged from −0.01 to 0.02, with a mean yield change in the −0.2 % to 0.8 % range for corn and soybean-producing counties. Overall, 48 % of corn-producing counties declined in conditions and yield, while 49 % of soybean-producing counties declined in conditions and yield during July—highlighting the influence of additional factors that shape crop response within a derecho-affected area.

In August, as corn transitions toward physiological maturity and soybeans reach their peak pod-setting stage, declines in crop condition and yield become more pronounced, similar to the declines experienced during June (Fig. 5). During August, corn begins the grain filling process, where kernel weight is determined, making it particularly vulnerable to late-season stressors (Bayer, 2020). Meanwhile, soybeans enter their most critical phase for pod development and seed filling, where adverse conditions can significantly reduce pod retention and seed size (Nleya et al., 2019). By the end of August, crop conditions accounted for nearly 90 % of the variance in corn yield anomalies and 80 % of soybean yield anomalies at the national level (Bundy et al., 2024). Mean CCIndex changes ranged from −0.02 to −0.07, with a yield change mean in the −0.5 % to −2.5 % range for corn and soybean-producing counties, with CCIndex rating changes as low as −1.29 and yield changes as low as −22 %. Overall, 61 % of corn-producing counties declined in conditions and yield, while 56 % of soybean-producing counties declined during August. When just examining crop condition and yield changes following a derecho on a monthly basis, the observed near-equal probabilities of change in both corn and soybean-producing counties suggest that factors in combination with phenology warrant further examination.

3.2.2. High winds and heavy precipitation

Within a derecho footprint, a total of 8 % of corn- and soybean-producing counties recorded a wind gust of ≥ 120 kph when considering all 79 storm footprints. Of these counties, nearly 60 % of them declined in condition and yield, making the impact magnitude of high winds on crop conditions and yield based on the timing of the derecho. Overall, there was an observed declining trend in conditions and yield deltas throughout the warm season for counties that experienced a ≥ 120 kph wind gust, which mirrored the overall trend across all counties within each derecho (Fig. 5), albeit with a more pronounced detrimental effect (Fig. 6). In May and June, Week 2 CCIndex and yield changes showed improvement compared to Week 1, whereas Week 2 changes in July and August were more severe than those in Week 1. This pattern highlights the greater potential for crop recovery earlier in the growing season, while later-season impacts tend to be less reversible and more detrimental. During the vegetative stages of corn and soybean development in May and June, mean CCIndex impacts ranged from −0.01 to −0.03 immediately following a derecho in Week 1 (yield changes ranged from −1.2 % to −2.4 %), with some extent of improvements observed during Week 2, as CCIndex changes ranged from −0.01 to 0.02 (yield changes ranged from −0.5 % to 0.8 %). For corn and soybeans, root lodging—when plants fall over due to root anchoring failure without stalk or stem breakage—is the most common wind-related damage during early vegetative stages, especially in fields containing poorly developed root systems (Barnes et al., 1992; Licht and Clemens, 2023; Thomison, 2016). Beyond developmental limitations, other agronomic factors, such as corn rootworm feeding, can further compromise root anchorage and increase lodging risk with excessive winds. Similarly, the susceptibility to greensnap—complete stem breakage at the node—varies with developmental timing, with plants in the mid-vegetative growth stages particularly prone to snapping near the soil surface. For soybeans, wind-related damage is equally concerning through the growing season, as plants that are cut below the cotyledon cannot recover, resulting in complete yield loss (Brhel et al., 2022).

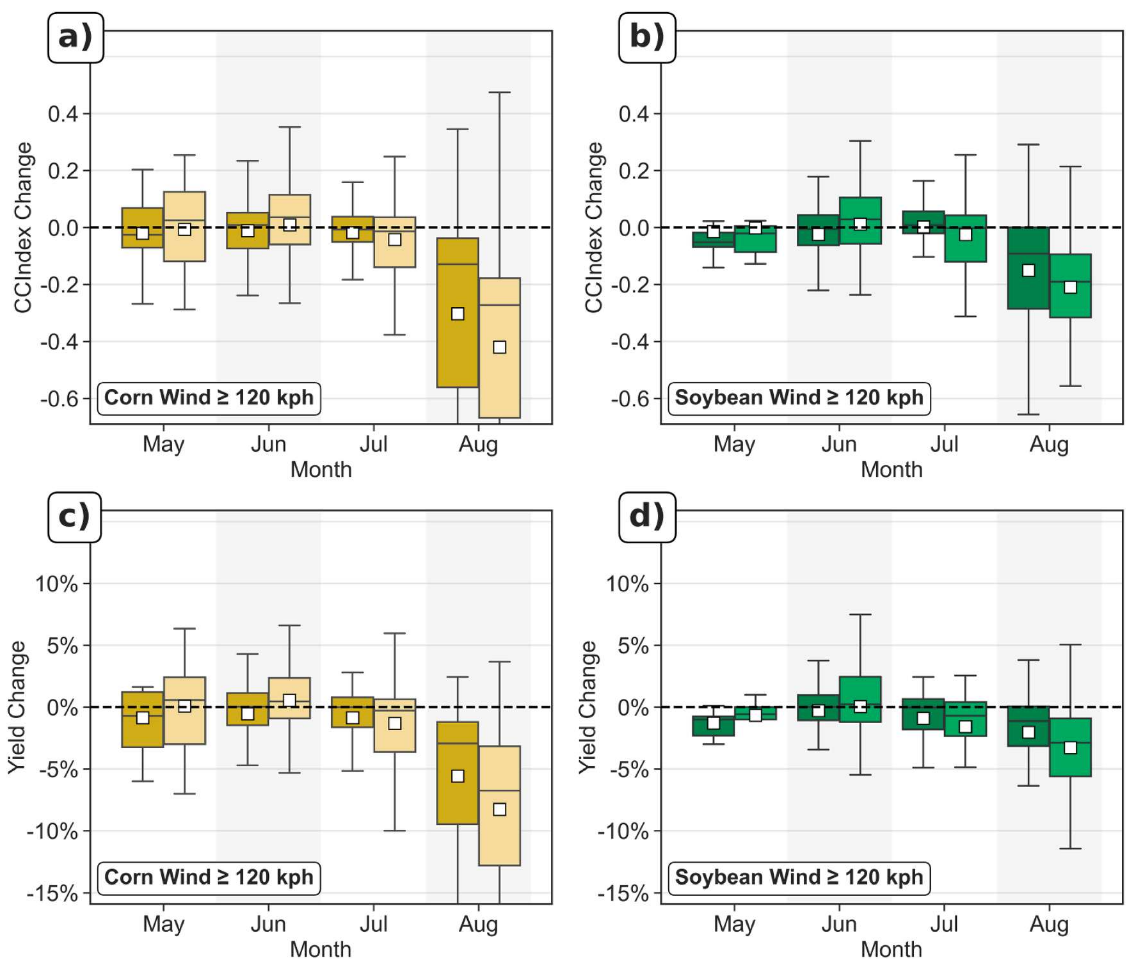

Fig. 6. Box and whisker plots of week 1 (darker shade) and week 2 (lighter shade) CCIndex deltas from week 0 for each derecho that impacted a) corn counties and b) soybean counties. Only the counties that contained *a* ≥ 120 kph reported wind gust are included. Yield deltas (measured as percent change) of week 1 and week 2 derecho impacts are represented by month for c) corn and d) soybeans. Each box and whisker present the same six number summary as described in Fig. 5.

In July, impacts were more severe in the two weeks following a derecho, as mean county-level CCIndex changes for both crops ranged from 0.00 to −0.06 and corresponding mean yield changes ranged from −1.0 % to −2.8 % when isolated to only the counties with high wind reports (Fig. 6). August exhibited the most severe derecho impacts to corn and soybeans when isolating to just the counties that experienced a high wind gust (≥ 120 kph), as mean corn CCIndex changes ranged from −0.25 and −0.42, while soybean CCIndex changes ranged from −0.17 to −0.20, both crops contained statistically significant changes at the 95 % significance level. These condition declines also translated to statistically significant, mean yield changes of −5.5 % to −8.0 % for corn and −2.3 % to −3.8 % for soybeans. In total, 89 % of corn and soybean-producing counties that experienced a ≥ 120 kph wind gust during a derecho declined in condition and yield in August. Furthermore, August was the only month in which the interquartile range of crop impacts was entirely negative for both condition and yield changes, suggesting that derechos occurring during reproductive stages have a distinctly greater potential for county-level yield losses if undergoing a high wind gust. While root lodging is more common during early vegetative stages, it can also occur in reproductive stages, as demonstrated by widespread corn and soybean lodging during Iowa's 10 August 2020 derecho (Gramling, 2020). When stalk lodging occurs during the corn grain-filling period in August, previous controlled field experiments demonstrated that it could result in substantial yield reductions—annual corn losses ranging from 5 % to 25 % (Stubbs et al., 2020; Xue et al., 2017). In severe cases, yield losses of up to 50 % have been reported when lodging occurs during this critical developmental phase (Li et al., 2015; Xue et al., 2017).

Approximately 6 % of corn- and soybean-producing counties within the derecho's footprint received a county-mean of ≥ 50 mm of precipitation during the storm's duration across all 79 derecho footprints. The impact of heavy precipitation on corn and soybeans remained relatively consistent throughout the warm season, with mean CCIndex and yield changes around zero (Fig. 7). However, August was an exception for corn, with mean CCIndex changes of −0.10 and corresponding yield changes of −2.6 %. For soybeans, May was the only month when conditions improved on a mean basis, with a CCIndex change of 0.01 in Week 1 and 0.06 in Week 2. While the mean impact of heavy precipitation was similar between corn and soybeans, the distribution of effects varied significantly. Soybeans exhibited the greatest variability, experiencing both the most substantial improvements and the most severe declines in crop conditions and yield in response to heavy precipitation from a derecho. This heightened variability in soybean response is driven by several physiological and developmental factors, including a shallow root system that limits nutrient uptake in waterlogged soils and increases susceptibility to oxygen deprivation (Pasley et al., 2020). Another key distinction between corn and soybeans lies in reproductive development: corn flowers only once, creating a narrow window of vulnerability, whereas soybeans flower over an extended period, allowing late-season precipitation to offset early stress and improve conditions after a derecho in some cases. Excessive precipitation alone did not consistently harm crop conditions or yield, but its interaction

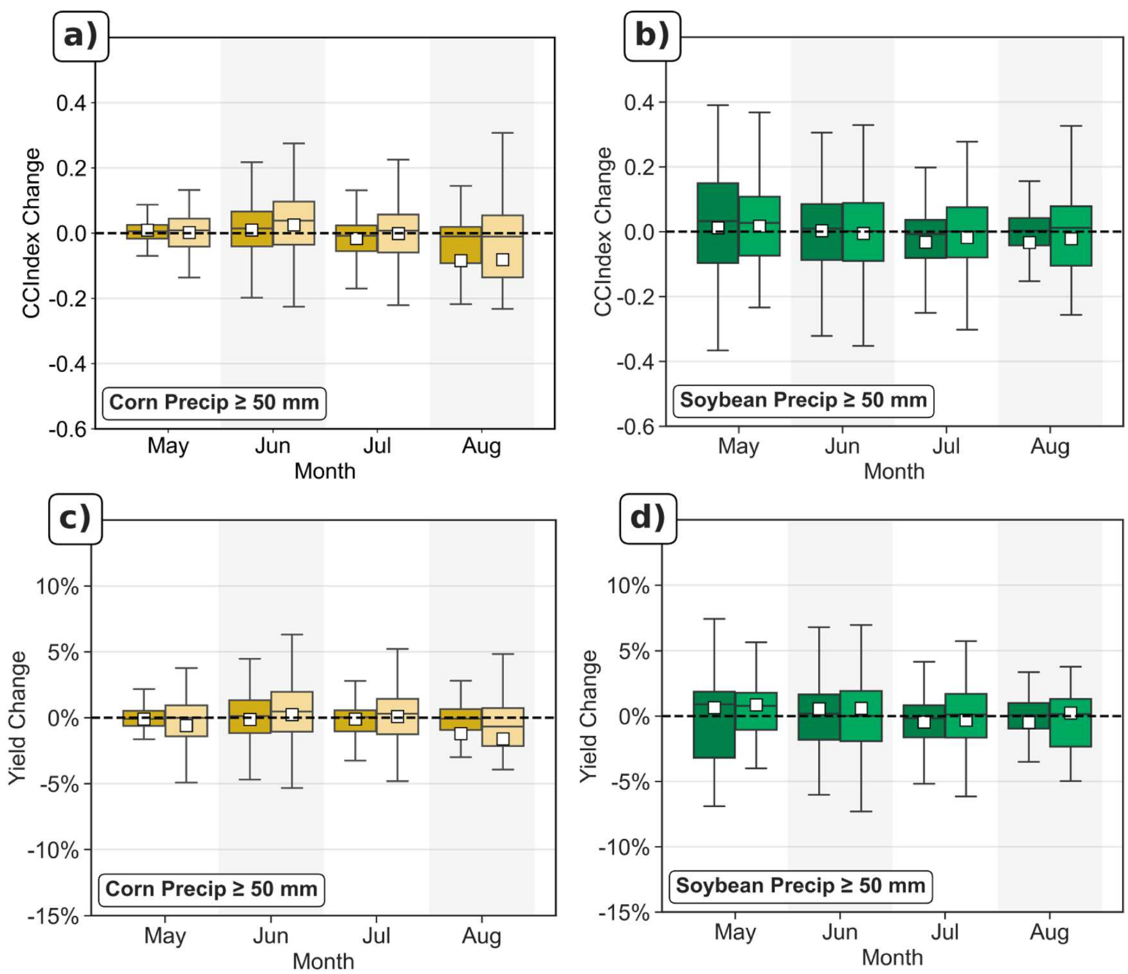

Fig. 7. Box and whisker plots of week 1 (darker hue) and week 2 (lighter hue) CCIndex deltas from week 0 for each derecho that impacted a) corn counties and b) soybean counties. Only the counties that underwent ≥50 mm of precipitation are included. Yield deltas (measured as percent change) of week 1 and week 2 derecho impacts are represented by month for c) corn and d) soybeans. Each box and whisker present the same six number summary as described in Fig. 5.

with phenology and high winds often exacerbated damage. In August, all the counties that experienced both ≥ 50 mm of precipitation and a wind gust of ≥ 120 kph declined in condition, indicating a compounding effect, and reinforcing the multifaceted nature of derecho impacts.

3.2.3. Precursor conditions

Beyond the immediate impacts of a derecho, preexisting growing conditions influence how crops respond and recover from the storm. One key preexisting growing condition is soil moisture, as antecedent conditions may alter a crop's resilience or vulnerability to derecho-related stressors with an existing 0.60 correlation coefficient between the PDSI and crop condition ratings (Bundy and Gensini, 2022). The impact of preexisting moisture extremes followed a general pattern of linear condition and yield changes for corn and soybean crops (Fig. 8). In May, counties with a PDSI ≤ −3.0 (severe drought) or ≥ 3.0 (excessive wetness) prior to a derecho experienced a mean improvement in both corn and soybean CCIndex ratings, ranging from 0.12 to 0.27, with corresponding yield increases of 1.1 % to 6.3 %. With 80 % of corn- and soybean-counties improving in conditions and yield after a derecho under preexisting moisture extremes in May, derechos can provide a beneficial moisture reset in regions suffering from severe drought or maintain crop conditions under excessive wetness. However, in areas already experiencing excessive wetness in May, prolonged saturation can lead to oxygen deprivation, root diseases, and stand reductions during the early season (Li et al., 2019). This vulnerability is exacerbated in poorly drained soils, where waterlogging can persist, hindering nutrient uptake and leading to declines in crop health and yield (Li et al., 2019; Liu et al., 2023).

By June, preexisting dry conditions continued to support improvements in both corn and soybeans following a derecho (mean CCIndex changes ranged from 0.01 to 0.12; mean yield changes ranged from 0.01 % to 1.4 %). Meanwhile, excessive wetness led to subtle declines on a mean basis following a derecho during June for both crops (mean CCIndex changes ranged from −0.01 to −0.02; mean yield changes ranged from 0.0 % to −1.6 %). In July, the effects diverged between the two crops—corn experienced its most significant declines under preexisting drought conditions, when stress during the flowering stage is especially detrimental to development and yield (mean CCIndex changes ranged from −0.01 to −0.10; mean yield changes ranged from −1.3 % to −6.4 %). Excessive moisture, by contrast, resulted in only minor reductions in corn conditions and yield following a derecho. After prolonged drought stress, a sudden influx of moisture may not be readily used by the crop, as drought-stressed plants often have reduced root function and diminished leaf area, limiting their ability to recover quickly (Li et al., 2019; Zhang et al., 2025). Additionally, corn that has endured significant dryness is more susceptible to lodging, further exacerbating declines in crop condition and yield potential (Carter and Hudelson, 1988; Pioneer, 2024). In contrast, soybean conditions either subtly improved or remained stable after a derecho in July under extremely dry or wet precursor conditions.

By August, the influence of dryness prior to a derecho was generally minimal for both corn and soybeans. However, both excessive dryness and wetness led to declines in both condition and yield, with mean CCIndex mean changes as low as −0.17 and yield mean changes as low as −3.2 % (Fig. 8). Wind-lodged root systems may be uprooted with minimal breakage—often occurring in dry soils with reduced integrity that limit root anchorage due to shallow root development—or through root breakage (Carter and Hudelson, 1988; Erndwein et al., 2020). Additionally, heightened vulnerability in corn and soybeans under wet conditions is likely due to increased susceptibility to root diseases and rot, which are exacerbated by prolonged soil saturation (Lindsey et al., 2024; Pasley et al., 2020). Excessive precipitation can cause pod splitting in soybean crops, which is especially problematic if the excessive precipitation followed a dry spell (Vann and Strokes, 2020). Also, when excessive wetness was juxtaposed with high wind gusts (≥ 120 kph) across the entire warm season, CCIndex means declined by 0.11 among both crops.

Among the various factors examined, precursor crop conditions—referring to crop conditions during the week prior to the derecho—exhibited the strongest explanatory power (38 %) in crop condition changes and most months displayed statistically significant changes in CCIndex ratings and subsequent yield changes (Fig. 9). Except for Week 1 soybean changes in May, derechos generally led to improvements in mean corn and soybean conditions when precursor CCIndex ratings were ≤ 3.0, with mean CCIndex changes ranging 0.03 to 0.20 and mean yield changes ranging from 0.1 % to a 6.5 % increase. Based on USDA definitions of crop conditions (USDA, 2016), a CCIndex of ≤ 3.0 represents crops being in fair or worse condition, which may lead to some extent of yield loss. Therefore, this suggests that crops in suboptimal condition prior to derecho have a greater probability of benefitting from a derecho due to the precipitation such events bring. A total of 62 % of corn- and soybean-producing counties improved in condition and yield after a derecho when precursor CCIndex ratings were ≤ 3.0. These lower initial CCIndex ratings typically reflected either antecedent dryness (PSDI < 0.0), or, in some cases, excessively wet conditions (PDSI ≥ 3.0). In 90 % of such cases, crop conditions improved after the derecho, primarily due to precipitation alleviating dryness or if maximum wind gusts and/or precipitation totals were not excessive enough to continue negatively impacting the crop. Conversely, when precursor CCIndex ratings were ≥ 4.0, indicating crops were in good or excellent condition and likely to have normal or above normal yield prospects, crop conditions and yield generally declined or remained steady following a derecho (Fig. 9). Mean CCIndex changes ranged between −0.19 to 0.05 for corn and soybeans, while yield changes ranged from −3.8 % to 0.1 %. This decline is a result of high exposure of optimal crops to the detrimental effects of high wind gusts—leading to lodging, defoliation, and mechanical damage to plants that were previously thriving, and the effects of excessive precipitation—leading to temporary waterlogging, reducing oxygen availability to the root zone and stressing plants.

3.3. Crop recovery

From the time a derecho occurred, through the end of the growing season, crop recovery became increasingly limited (Fig. 10). Across all months, mean crop conditions and yield prospects exhibited sustained declines, with CCIndex changes through the remainder of the season ranging from –0.03 to –0.30 (Fig. 10a) and yield losses between –1.3 % and –5.4 % for both crops (Fig. 10b). In total, 56 % of corn- and soybean-producing counties affected by a derecho experienced deteriorating conditions from Week 2 onward. For corn, the most pronounced CCIndex declines occurred in May and June, with a mean rating change of −0.30 and corresponding yield change of –3.7 %. By July and August, condition declines were less severe, with mean CCIndex changes ranging from –0.02 to –0.10 and yield reductions between –0.1 % and –2.8 %. In contrast, soybean CCIndex changes remained relatively stable throughout the season, with only a subtle degradation in quality through harvest. Variability in corn and soybean condition changes through the growing season was highest during early vegetative stages, with standard deviations in CCIndex reaching 0.20 and yield variability ranging 6.4 %, indicating a wider range of outcomes by harvest. However, as crops advanced toward maturity, this variability decreased to 0.15 for the CCIndex and 4.3 % for yield, indicating a reduced capacity for recovery from derecho-induced stress. By August, when derecho impacts were predominantly negative (Figs. 5–9), crop recovery was minimal. The continued decline in conditions through harvest reflects the broader climatology of crop conditions, as corn and soybean mean CCIndex ratings typically decrease from emergence to harvest by 0.15 and 0.10 at the national level, respectively (Bundy et al., 2024). Beyond derechos, additional adverse weather events—including drought, hailstorms, and flooding—contribute to this seasonal degradation. Notably, the most significant seasonal transition in crop conditions occurred from June to

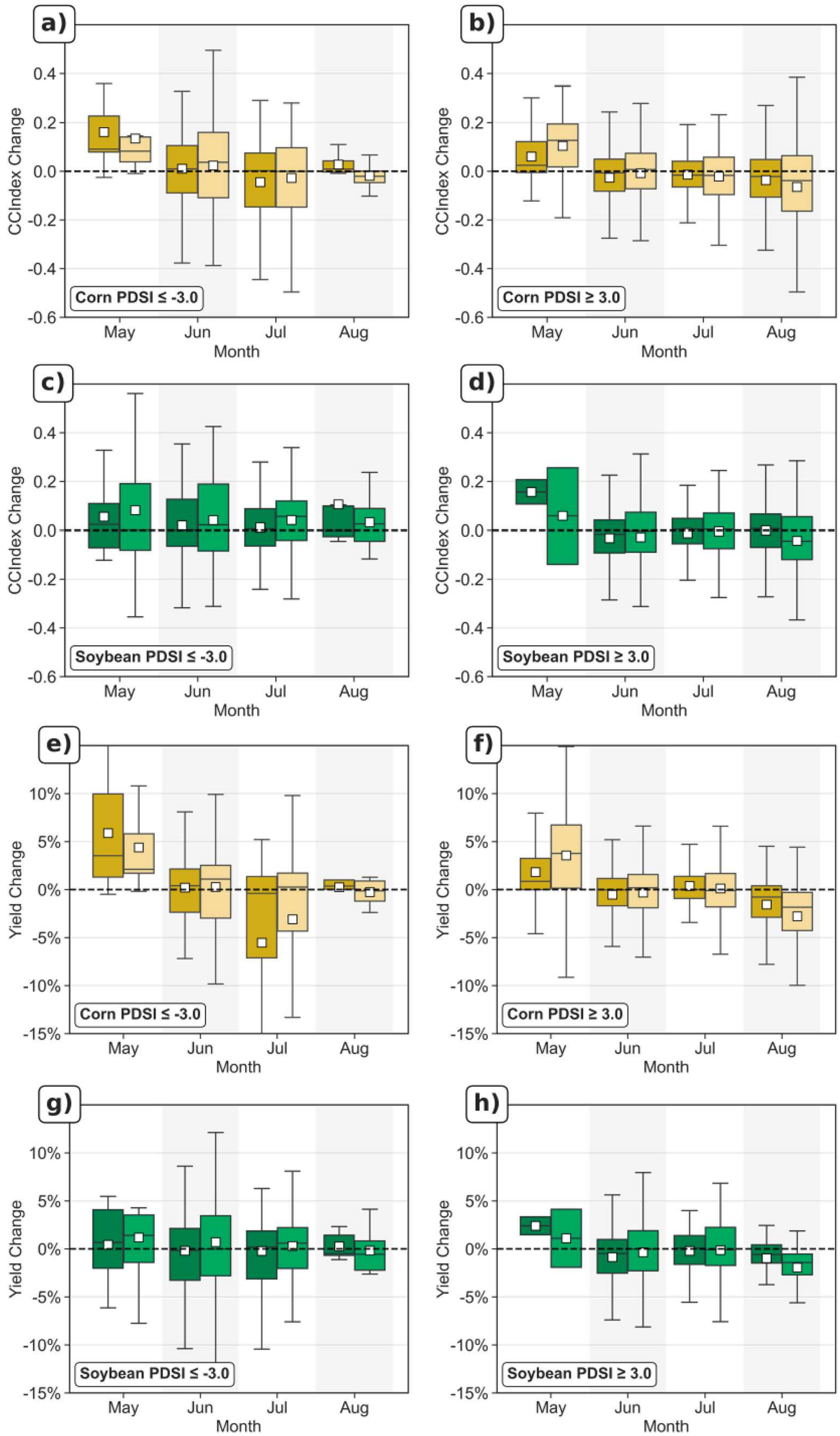

Fig. 8. Box and whisker plots of week 1 (darker hue) and week 2 (lighter hue) CCIndex deltas from week 0 for each derecho that impacted a) corn counties with PDSI values ≤ −3.0; b) corn counties with PDSI values ≤ −3.0; c) soybean counties with PDSI values ≥ 3.0; and d) soybean counties with PDSI values ≥ 3.0. Yield deltas (measured as percent change) of week 1 and week 2 derecho impacts are represented by month (e–h) in the same orientation as the CCIndex delta panels (a–d). Each box and whisker present the same six number summary as described in Fig. 5.

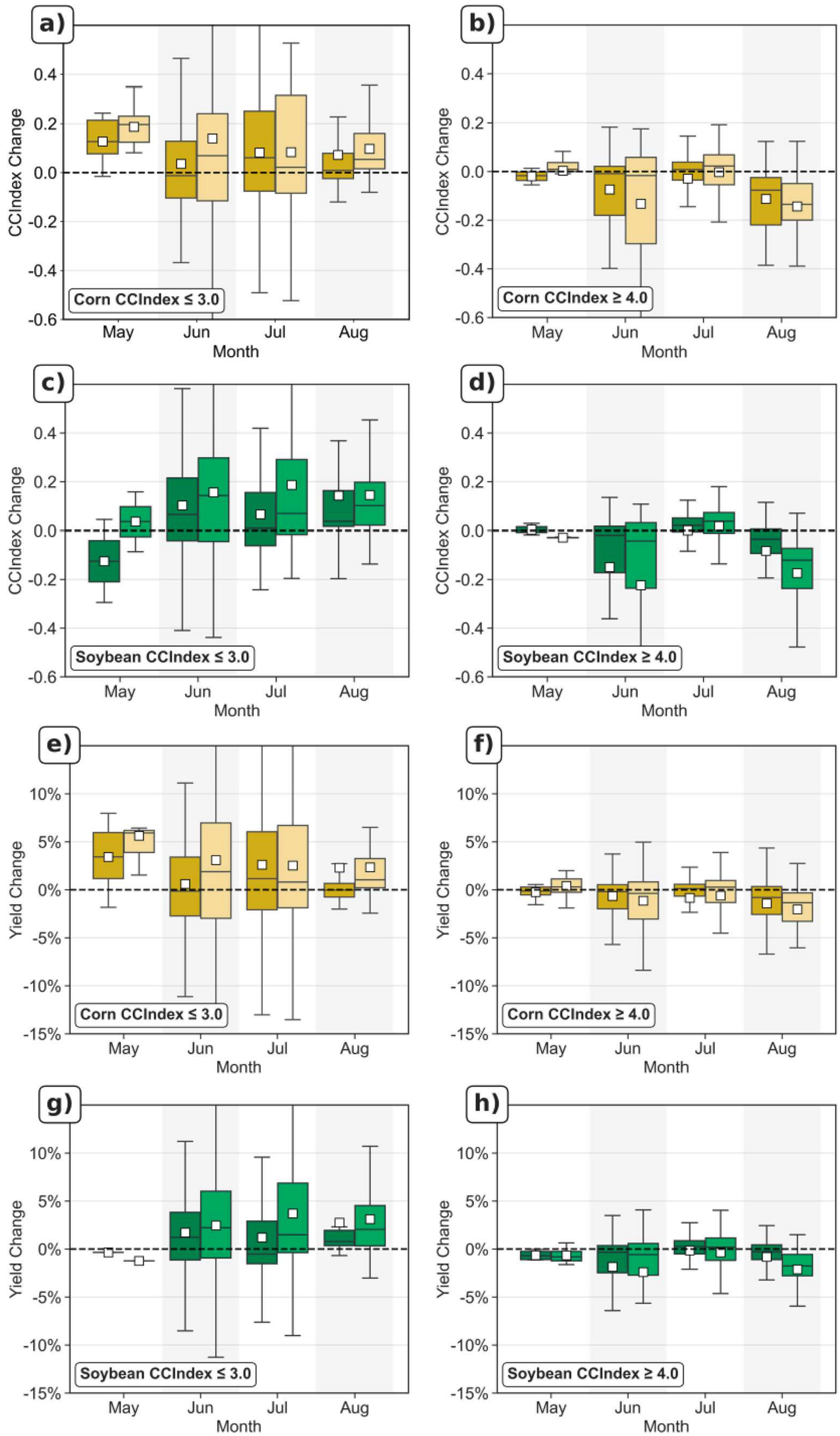

Fig. 9. Box and whisker plots of week 1 (darker hue) and week 2 (lighter hue) CCIndex deltas from week 0 for each derecho that impacted a) corn counties with precursor CCIndex values ≤ 3.0; b) corn counties with precursor CCIndex values ≥ 4.0; c) soybean counties with precursor CCIndex values ≤ 3.0; and d) soybean counties with precursor CCIndex values ≥ 4.0. Yield deltas (measured as percent change) of week 1 and week 2 derecho impacts are represented by month (e–h) in the same orientation as the CCIndex delta panels (a–d). Each box and whisker present the same six number summary as described in Fig. 5.

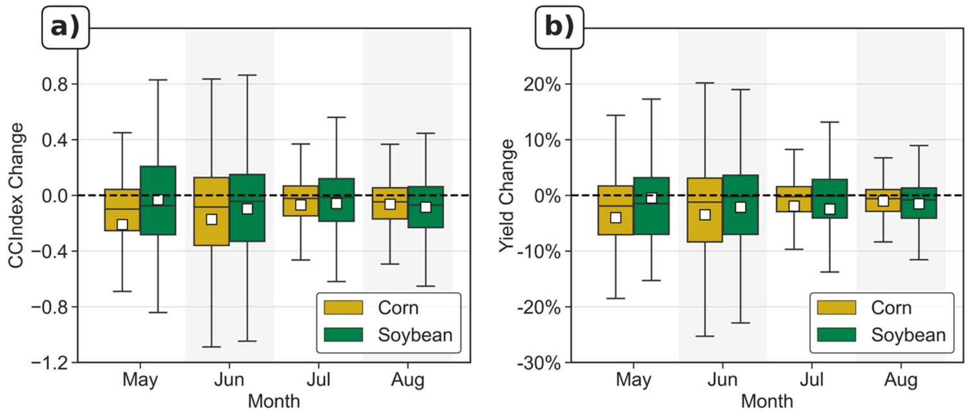

Fig. 10. Box and whisker plots of corn and soybean recovery represented by a) CCIndex deltas from the mean between the week 1/week 2 CCIndex ratings and the final growing season week's CCIndex rating; b) deltas between the mean of the week 1/week 2 modeled yield and the end of growing season observed yield. Each box and whisker present the same six number summary as described in Fig. 5.

July, coinciding with corn's peak silking stage and soybean pod setting, during which extreme weather events have lasting impacts on yield potential (Bundy et al., 2024; Irwin and Good, 2017a; Westcott and Jewison, 2013). The reduction in variability between June and July suggests that crops enter a more deterministic phase of development, where external stressors, such as derechos, become more influential in shaping final yield outcomes. Additionally, when crops experienced a decline in condition following a derecho, the mean CCIndex remained lower for the remainder of the growing season, with a mean change of −0.13 compared to the −0.06 CCIndex change when crops improved following a derecho. This exacerbation suggests that derecho-induced stress not only causes immediate damage but also hampers recovery, due to structural crop damage and increased susceptibility to secondary stressors such as drought, disease, or pest infestations. The compounded effects of these factors likely contribute to a prolonged reduction in crop conditions and overall productivity throughout the remainder of the growing season.

4. Summary and conclusions

By using a storm-tracking algorithm, severe convective wind reports, and derecho criteria to identify derecho footprints and integrate them with weekly USDA NASS crop condition data, this study quantified changes in crop conditions and modeled yield estimates within derecho footprints; evaluated the effects of these changes based on factors such as phenological stage, wind and precipitation magnitude, location, and precursor crop and climatic conditions; and analyzed how derechos impact crop recovery throughout the growing season. Over the nine-year study period, county-level corn and soybean CCIndex deltas reached as low as −1.36, with yield reductions as severe as 37 % following a derecho. Notably, some of the most severe declines in conditions and yield from a derecho were comparable to the impacts from hurricanes. However, the impact of these events was heterogeneous across affected regions. While nearly half of the counties within a given derecho footprint experienced declines in both condition and yield, the other half either maintained or improved, highlighting the complex and variable nature of derecho impacts. This variation suggests that multiple interacting factors—such as location, crop growth stage, storm magnitude, preexisting crop and climatic conditions, and post-event weather patterns—collectively shape overall crop response.

Derechos impacted a mean of 1.5 million ha of corn and soybeans (4.3 % of national production) per storm footprint. At least one corn- and soybean-producing county was affected by each derecho during the warm season over the 2015–2023 period, with 75 % of these counties negatively impacted at least once. Spatially, the juxtaposition between the highest exposure of corn and soybeans and highest frequency of derechos was across the Corn Belt, which led to a greater vulnerability to detrimental impacts. Temporally, the highest frequency of derechos during the warm season did not equate to increased crop loss vulnerability, as it was the interaction of the aforementioned factors that influenced crop condition response and recovery. Crop areas that experienced reported wind gusts ≥ 120 kph were more likely to exhibit condition declines, with the magnitude of degradation generally increasing as crops progressed through vegetative and reproductive stages. Particularly for corn, condition vulnerability was further amplified when severe wind gusts coincided with late-season drought or excessive wetness. Additionally, impacts from derechos were largely governed by pre-derecho crop conditions, as crops in suboptimal condition prior to a derecho were more likely to improve when the storm delivered sufficient precipitation to relieve antecedent stress. The inverse was also true, in that the higher exposure of crops that were in optimal condition for normal or above normal yield prospects, the more likely the crop was negatively impacted by the storm. For crop recovery, conditions typically declined following a derecho through the remainder of the growing season. However, declining conditions through the season were exacerbated if a derecho caused conditions and yield prospects to decline immediately after the storm.

As the frequency of extreme weather events increases, data-driven decision-making is critical for safeguarding agricultural productivity and resilience. There is an urgent need for effective management strategies to mitigate the impacts of derechos on crops, requiring proactive planning, systematic field assessments, and adaptive interventions. Future research should refine the understanding of how factors such as crop development stage, stress severity, and management practices influence yield responses to derechos across a range of crop types. Furthermore, advancements in predictive modeling could enhance the ability to forecast CCIndex and yield changes at the county level prior to derecho events, providing stakeholders with a proactive risk assessment framework to inform management decisions; importantly, such efforts should explicitly account for crop development stage, given its critical role in mediating crop vulnerability to storm damage. Although future derecho-related agricultural and economic risks are uncertain, future research may also investigate how shifts in derecho frequency and intensity under changing climate conditions interact with the evolving the crop landscape to better quantify economic impacts. By integrating comprehensive analyses of past derecho events and other extreme weather hazards, the agricultural sector can develop adaptive strategies that enhance resilience, minimize yield losses, and ultimately contribute to a more sustainable and climate-resilient agricultural future.

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Logan R. Bundy: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Kristie N. Kaminski:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Alex M. Haberlie:** Writing – review & editing, Validation, Supervision, Methodology, Data curation, Conceptualization. **Walker S. Ashley:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition. **Vittorio A. Gensini:** Writing – review & editing, Validation, Supervision, Project administration, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.agrformet.2025.110913.

Data availability

Data will be made available on request.

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