Received: 31 July 2025 | Accepted: 17 May 2026

DOI: 10.1002/agj2.70454

Agronomy Journal

ORIGINAL ARTICLE

Crop Economics, Production, and Management

Yield gap analytics in maize production for Texas agricultural district and state levels

Bala Ram Sapkota[1,2] | **Gurjinder S. Baath**[1,2] | **Ronnie W. Schnell**[2] | **Jagmandeep S. Dhillon**[3] | **Seth C. Murray**[2] | **K. Colton Flynn**[4]

[1]Blackland Research & Extension Center, Texas A&M AgriLife Research, Temple, Texas, USA

[2]Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas, USA

[3]Department of Plant and Soil Science, Mississippi State University, Starkville, Mississippi, USA

[4]USDA-ARS Grassland Soil and Water Research Laboratory, Temple, Texas, USA

Correspondence
Gurjinder S. Baath, Blackland Research & Extension Center, Texas A&M AgriLife Research, 720 E. Blackland Rd, Temple, TX 76502, USA.
Email: gurjinder.baath@ag.tamu.edu

Assigned to Associate Editor Wei Hu.

Abstract

Maize (*Zea Mays* L.) is a globally important crop with significant economic and nutritional value. Closing its existing yield gap—the difference between potential and farmers' achieved yields—is critical for enhancing food security and agricultural sustainability. The objectives of this study were to evaluate yield trends and quantify yield gaps in Texas maize production at both the state and agricultural district levels using data from 2014 to 2023. Actual maize yield (*Ya*) data were obtained from United States Department of Agriculture–National Agricultural Statistics Service, while irrigated yield (*Yi*) and rainfed yield (*Yr*) were sourced from Texas A&M AgriLife variety trials. Contest yield (*Yc*), representing maximum attainable yield, was derived from the National Corn Grower Association database. Historical analysis (1860–2023) revealed a 10-fold increase in both the US and Texas maize yields. However, over the past decade, yields across all production scenarios (*Yc*, *Yi*, *Yr*, and *Ya*) and resulting yield gaps in Texas have remained stagnant. At the state level, average yield gaps were 40.87% between *Yc* and *Ya* (*Yg1*), 30.11% between *Yi* and *Ya* (*Yg2*), and −13.01% between *Yr* and *Ya* (*Yg3*). Among agricultural districts, the Blacklands exhibited the largest yield gaps, with *Yg1* at 58% and *Yg3* at 37.55%, while the Northern High Plains achieved the highest maize yields (*Yc*, *Yi*, and *Ya* scenarios), with *Yg1* and *Yg2* at 21.91% and 18.94%, respectively. These findings highlight the need for stress-tolerant genotypes and adoption of region-specific agronomic practices to reduce yield gaps and enhance productivity of maize systems.

Plain Language Summary

Historically, U.S. and Texas maize yields have increased dramatically but have remained stagnant in Texas in last decade. This study looked at maize grain yield and yield gap from 2014-2023, comparing production field yields to potential yields across the maize growing region of the Texas. On average, Texas producers produce about 40% less maize grain than what's potentially achievable. Irrigated fields still

Abbreviations: NASS, National Agricultural Statistics Service; NCGA, National Corn Grower Association.

yield about 30% less than their potential. Some regions, like the Blacklands, have very large yield gaps, while the Northern High Plains show higher yields and smaller gaps. To improve Texas maize production and reduce the yield gaps, region-specific crop management strategies and improved genotypes are necessary.

1 | INTRODUCTION

Maize (*Zea mays* L.), also known as corn, is a globally important crop with significant economic and nutritional value. In 2024, maize was cultivated on over 207 million ha worldwide, producing about 1.22 billion Mg of grain (Food and Agriculture Organization of the United Nations, 2024; Ritchie et al., 2025). In the United States, maize is a principal cereal crop, with 33.5 million ha harvested and a production total approaching 378 million Mg of grain in 2024 (USDA–NASS, 2025). While the Midwest region dominates US maize production, Texas plays a vital role in the national output and stands as the leading maize producer among the US southern states. In 2024, Texas accounted for 22.9% of maize production among the southern states, followed by Kentucky (18.4%), Tennessee (12.1%), and North Carolina (10.5%) (USDA–NASS, 2025).

According to the United States Department of Agriculture (USDA) November Crop Report, Texas harvested approximately 850,000 ha in 2023, producing about 6.5 million Mg and an average maize yield of 7.7 Mg ha^{-1}. In 2024, Texas harvested about 765,000 ha, yielding about 5.8 million Mg with an average yield of 7.1 Mg ha^{-1} (USDA–NASS, 2025). However, this average yield varies largely across different maize-growing areas within Texas. Data from the USDA's National Agricultural Statistics Service (NASS), which combines survey and remote sensing estimates, highlight significant yield variability among counties, attributed to the state's diverse climatic regions and geographic heterogeneity. Variety testing trials conducted by Texas A&M AgriLife Extension evaluate a wide range of commercially available cultivars to provide growers with unbiased performance data based on head-to-head comparisons. In 2023, these variety trials reported yields ranging from 3.5 to 14.8 Mg ha^{-1}, with an average of 10.2 Mg ha^{-1} (Schnell et al., 2024). Similarly, yield contest data from the National Corn Growers Association (NCGA) showed average maize yields varying from 11.1 to 20.3 Mg ha^{-1}, with an average of 15.4 Mg ha^{-1} for the same year (NCGA, 2024).

Besides such variability, a previous analysis based on a decade of Texas maize variety (2001–2010) trials and respective USDA–NASS data revealed little improvement in varietal or actual yield across most regions of Texas (Barrero Farfan et al., 2013). Whether this trend has continued over the past decade and the extent to which weather or other external factors have contributed remains unclear.

Yield gap analysis is a valuable approach for identifying disparities between the yields under optimal conditions and those realized by producers. This approach calculates yield differences across various production levels and helps formulate strategies to bridge these gaps (van Wart et al., 2013). Previous studies applying yield gap analysis for major crops, such as maize, wheat (*Triticum aestivum* L.), and sorghum (*Sorghum bicolor* L. Moench) in other US regions, have been instrumental in identifying various biophysical and socioeconomic factors influencing yields, including weather variability, soil fertility, water availability, and management practices (Dhillon et al., 2022; Egli & Hatfield, 2014; Sexton-Bowser & Patrignani, 2024).

Yield gap analysis commonly employs four yield terms to assess production potential in a region: (1) irrigated yield (*Yi*), also known as potential yield, is the maximum attainable yield with best adapted hybrids under non-stressed environmental conditions (Fischer, 2015); (2) rainfed or water-limited yield (*Yr*) is the suggested crop yield benchmark when water availability is the sole limiting factor (Fischer, 2015; van Ittersum et al., 2013); (3) contest yield (*Yc*) represents the highest potential yield under farmer-managed conditions, which is reported by the NCGA (Lobell et al., 2009); (4) the actual yield (*Ya*) is the regional yield averages achieved by farmers, typically derived from USDA–NASS county-level data. Annual hybrid testing trials, conducted by state universities or extension programs, are commonly used to estimate *Yi* and *Yr* for a specific region or location (Dhillon et al., 2022; Patrignani et al., 2014). *Ya* could be used for comparison with *Yc*, *Yi*, and *Yr* to identify the yield gap at state or regional level and uncover factors contributing to yield gaps. For instance, the yield gap between *Yc* and *Ya* reflects the differences in agronomic management practices along with soil, topography, and other variables for a given production region.

Texas, with its vast geographical size and diverse climate regions, presents a unique opportunity to explore maize yield gaps at both state and county levels. However, the lack of hybrid trials in every county limits the feasibility of a detailed county-level yield gap analysis. Instead, grouping Texas counties into agricultural districts, as done by USDA–NASS, provides a more practical framework for comparison. The USDA–NASS groups Texas counties into 15 agricultural districts, and among these, four districts, namely Northern High Plains, Blacklands, South Central, and Upper Coast, are the major maize-producing regions (Figure 1) (USDA–NASS, 2025).

Understanding yield gaps at state and agricultural district levels can provide valuable insights into current production conditions and identify constraints to improving maize yields. Therefore, the main objectives of this study were to evaluate yield trends and quantify the existing yield gap for Texas maize at both the state and agricultural district levels. As no prior yield gap analysis exists for Texas maize production, this study serves as the first such attempt to calculate and interpret the yield gap, providing a foundational understanding to inform region-specific strategies aimed at optimizing maize productivity.

Core Ideas

- Texas maize yields stagnated over the past decade despite a century of significant historical gains.
- Large statewide yield gaps persist between potential and actual maize production in Texas.
- Yield gaps vary widely across Texas districts due to regional climate and management differences.
- Region-specific practices and improved hybrids are essential to boost maize yields in Texas.

2 | METHODOLOGY

2.1 | Data collection

Maize grain yield data for the United States and Texas from 1866 to 2023 were retrieved from the USDA–NASS database (USDA–NASS, 2024) to analyze and compare yield trends at both national and state levels. The USDA–NASS database provides extensive information on different crops, including cultivation area, harvested area, average yield, and economic metrics, compiled through crop surveys, remote sensing, and census data. The database for Texas also included additional variables such as average irrigated yield, average non-irrigated yield, average yield from 1980 to 2018, and average nitrogen application rates from 1991 to 2018. The variables enabled the analysis of long-term trends and their relationship with increasing nitrogen fertilizer application.

County-level actual yield data (*Ya*) for Texas were also retrieved from the USDA–NASS database. The database included annual yield estimates for individual counties with major maize production, while counties with minor production were aggregated under the "Other Counties" category. However, yield reporting for some major maize-producing counties was inconsistent, as some of these counties were occasionally classified under "Other Counties" in certain years. This inconsistency made it challenging to comprehend a complete yield gap analysis at the county level due to missing data points for some years. As a result, yield data were aggregated at the agricultural district level, which provided a more consistent and complete dataset over time.

Annual irrigated and rainfed maize yield data (*Yi* and *Yr*) were sourced from the Texas A&M University variety testing database (https://varietytesting.tamu.edu/corn/) (Schnell et al., 2024), while contest-level yield data (*Yc*) for Texas were obtained from the NCGA Corn yield contest database (NCGA, 2024). Both the hybrid variety testing and contest yield data were not necessarily associated with major maize-producing counties but corresponded more closely to agricultural districts, which further supported the study's approach of conducting yield gap analysis at the agricultural district level rather than the county level.

2.2 | Data analysis and visualization

Data organization and cleaning were performed using Microsoft Excel and the "*pandas*" package in Python. Yield growth trends of the maize at both the US and Texas state levels were identified and computed in Python using the "*pandas*" and "*scipy*" packages (McKinney, 2010). To contextualize these trends, data from 1866 to 1936 were grouped to represent the era of maize with open pollinated varieties. Similarly, data from 1937 to 1955 were grouped to represent the era of double-cross hybrids, while data from 1956 to 2023 represented the era of single-cross hybrids and modern maize varieties (Crow, 1998).

The slopes of linear regression equations were used as an estimate of the average annual change in maize grain yield during these distinct periods of maize development in both the United States and Texas. The statistical significance of the regression coefficient was tested at the 5% significance level. State-level data from 1980 to 2018 for irrigated and non-irrigated yield, as well as data from 1991 to 2018 for nitrogen application rates, were also used to compute and identify trends in maize yield and nitrogen usage during these periods. Visualizations of the identified trends were performed using "*matplotlib*" and "*scipy*" packages (Hunter, 2007; Virtanen et al., 2020).

Given the influence of recent technological advancements and the increasing variability in weather patterns, the yield gap analysis was restricted to the recent 10-year period, from 2014 to 2023 (Dhillon et al., 2022; Patrignani et al., 2014). At the state level, the yield gap analysis utilized all available *Ya* datapoints in the dataset. However, at the agricultural district level, the analysis was limited only to four agricultural districts, involving Northern High Plains, Blacklands, South Central, and Upper Coast, which collectively account for over 80% of maize production in Texas (USDA–NASS, 2025), and due to limited data availability from other districts (Figure 1). As per van Wart et al. (2013), 10 years of data representing at least 40%–50% production are considered sufficient to normalize year-to-year yield variability and accurately estimate yield gaps.

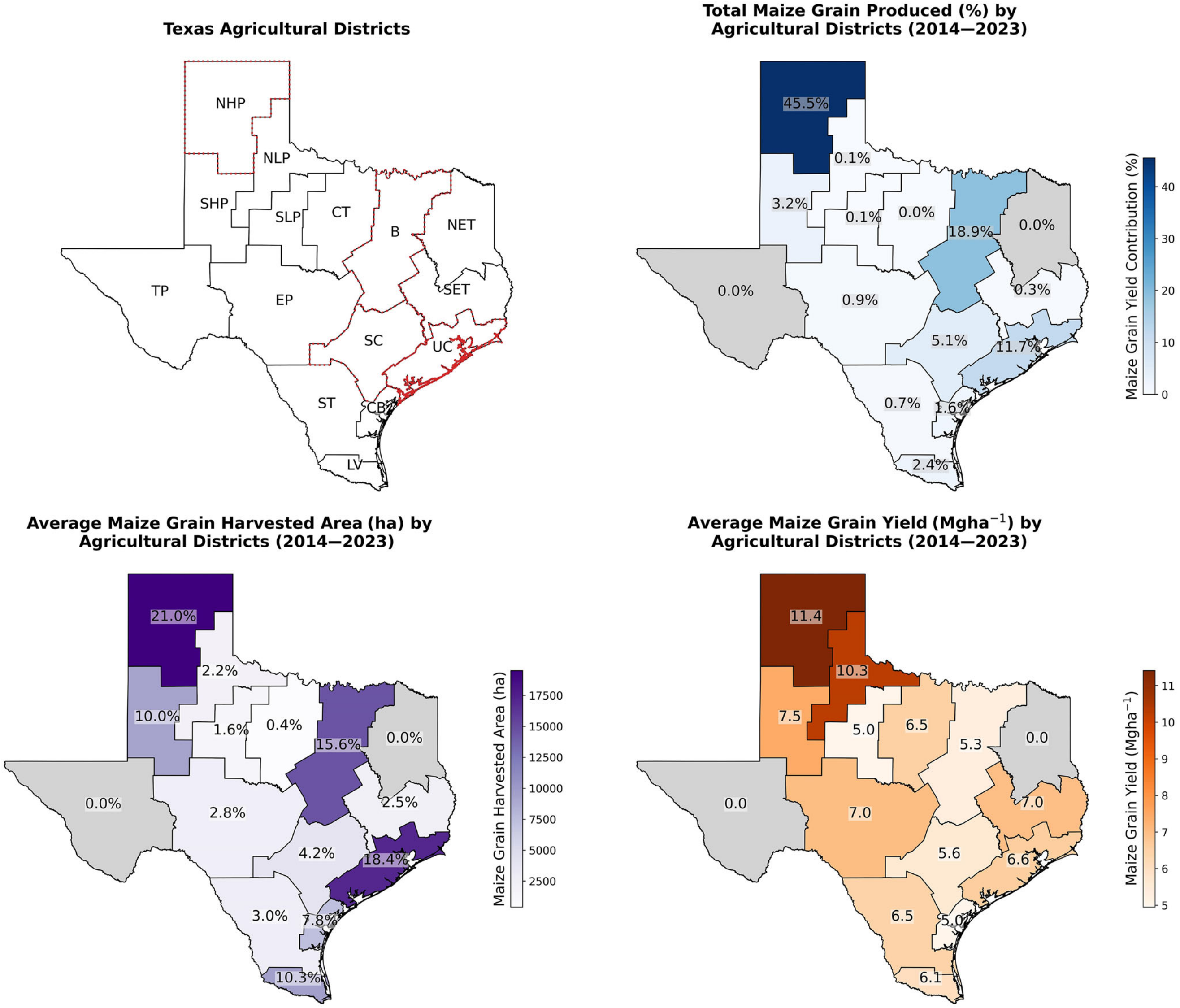

FIGURE 1 Top-left: state map of Texas showing the agricultural districts as divided by United States Department of Agriculture–National Agricultural Statistics Service (USDA–NASS). The highlighted agricultural districts in red outline contributed more than 80% of maize grain yield. Top-right: total maize grain produced in colors by each agricultural districts in 10 years (2014–2023). The number inside map denotes the percentage of total Texas production. Botton-left: average area (in hectares) of maize grain harvested in each agricultural districts in 10 years. The number inside map denotes the percentage of total Texas harvested area. Bottom-right: average maize grain yield (in Mg ha^{-1}) in each agricultural district in Texas in 10 years. B, Blacklands; CB, Coastal Bend; CT, Cross Timbers; EP, Edwards Plateau; LV, Lower Valley; NET, North East Texas; NHP, North High Plains; NLP, Northern Low Plains; SC, South Central; SET, South East Texas; SHP, Southern High Plains; SLP, Southern Low Plains; ST, South Texas; TP, Trans-Pecos; UC, Upper Coast. *Source*: USDA–NASS (2025).

At both the state and agricultural district levels, the maximum and 95th percentile values for *Yi*, *Yr*, *Yc*, and *Ya* were assessed for each year. The 95th percentile yield was used to mitigate the influence of outliers at all production levels when estimating yield gaps and their trends. Accordingly, the most yield gaps were calculated at three levels, as follows (Equations 1–3; Dhillon et al., 2022; Sexton-Bowser & Patrignani, 2024):

Gap between NCGA contest yield and NASS actual yield:

$$Yg1 = \frac{(Yc - Ya)}{Yc} \times 100\%. \tag{1}$$

Gap between irrigated variety trial yield and NASS actual yield:

$$Yg2 = \frac{(Yi - Ya)}{Yi} \times 100\%. \tag{2}$$

Gap between rainfed variety trial yield and NASS actual yield:

$$Yg3 = \frac{(Yr - Ya)}{Yr} \times 100\%. \quad (3)$$

It should be noted that *Yi* and *Yr* data were not available simultaneously for the same district; therefore, agricultural districts with available *Yc* and *Yi* data included the calculation of *Yg1* and *Yg2*, while districts with available *Yc* and *Yr* data included *Yg1* and *Yg3*. Visualizations of yield gaps, yield trends, and yield maps were performed using "*matplotlib*," "*scipy*," "*seaborn*," and "*geopandas*" packages in Python (Hunter, 2007; Jordahl et al., 2020; Virtanen et al., 2020; Waskom et al., 2017).

3 | RESULTS AND DISCUSSION

3.1 | Historical US and Texas state maize grain yield

Historical data from 1866 to 2023 showed that maize grain yield has overall increased more than fivefold in both the United States (≈1.7 vs. 11.1 Mg ha^{-1}) and Texas (≈1.5 vs. 7.7 Mg ha^{-1}) (Figure 2). However, during the open pollinated varieties era, spanning from 1866 to 1936, annual yield gains were not significant in either region (Figure 2). This period was characterized by limited genetic improvement and minimal technological interventions, including low fertilizer use and relatively modest agronomic inputs in maize production (Troyer, 1999).

The early 1930s marked the beginning of systematic maize breeding efforts led by land-grant universities, state agricultural experimental stations, and other public institutions (Hayes, 1956; Troyer, 1996, 2009). The introduction of double cross hybrids in mid 1930s improved annual yield gain by 55.9 kg ha^{-1} year^{-1} in the United States from 1937 to 1955 (Figure 2). In contrast, the annual grain yield gain during the same period in Texas remained modest (15.8 kg ha^{-1} year^{-1}). Hybrid maize adoption in Texas expanded from negligible acreage in 1940 to over 1.5 million acres by 1953, representing more than 74% of total maize acreage in the state. Despite this expansion, yield improvements remained limited, largely due to the poor adaptation of early hybrid varieties to Texas's environmental conditions, particularly the insufficient moisture availability during the latter part of the growing season (Bockholt & Collier, 1960; McAfee & Rogers, 1954).

From 1956 to 2023, the annual grain yield in the United States increased linearly at a rate of 119.3 kg ha^{-1} year^{-1}. During the same period, Texas experienced a comparable upward trend, with yields increasing at a rate of 101.3 kg ha^{-1} year^{-1} (Figure 2). The introduction of the improved maize single-cross hybrid varieties along with increased and efficient use of nitrogen (N) fertilizer, pesticides, and advancements in agricultural mechanization during the Green Revolution of 1960s contributed to this maize yield growth (Duvick & Cassman, 1999; Duvick, 2005). The enactment of the Plant Variety Protection Act in the 1970s further accelerated yield gains by incentivizing private-sector investment in maize research and development (Butler & Marion, 1984; Duvick & Cassman, 1999). However, most public and private investments for maize development (more than 80%) were concentrated in major maize-producing states of the Midwest. This regional focus contributed to higher national yield annual maize yield gains compared to Texas, where a smaller maize market limited research and development investments (Duvick & Cassman, 1999; Frey, 1996; Fuglie, 2000; Schimmelpfennig et al., 2004).

State-level data on average maize grain yield in Texas, based on irrigation practices, were available from 1981 to 2018 through the USDA–NASS database. Over this 37-year period, the state's average yield (combining irrigated and rainfed maize) increased annually by around 50 kg ha^{-1} year^{-1} (Figure 3). During the same period, irrigated maize experienced an annual yield growth of about 100 kg ha^{-1} year^{-1}, whereas non-irrigated maize grain yield remained statistically unchanged.

Interestingly, during this 37-year period, the average N application rate (kg ha^{-1}) in Texas remained statistically stagnant (Figure 3). This suggests that while the sharp yield gains observed during the 1960s could be driven by the adoption of both higher rates of nitrogen fertilizer applications and improved hybrids (Figure 2), the yield improvements after the 1980s were largely due to gradual improvement in field management practices and the continued development of improved maize hybrids (Duvick & Cassman, 1999; Schimmelpfennig et al., 2004).

3.2 | Yield gap and production trends at state level

Over the past decade (2014–2023), maize grain yield in Texas has remained statistically stagnant (though numerically decreased) across all production situations — *Yc*, *Yi*, *Yr*, and *Ya* (Figure 4). This stagnation mirrors findings from Mississippi, where similar trends in *Yc*, *Yi*, and *Ya* were reported between 2012 and 2021 (Dhillon et al., 2022). Globally, about 26% of maize-producing areas have experienced yield stagnation since the 2000s (Ray et al., 2012).

In Texas, the upper limit of maize grain yield (*Yc*) over the last decade was 20.8 Mg ha^{-1} under optimal production scenarios, while the lower limit of production (*Yr*) was 10.7 Mg ha^{-1} under water-limited conditions (Figure 5). *Yi* was noted to be 17.6 Mg ha^{-1}, and the actual yield (*Ya*) was

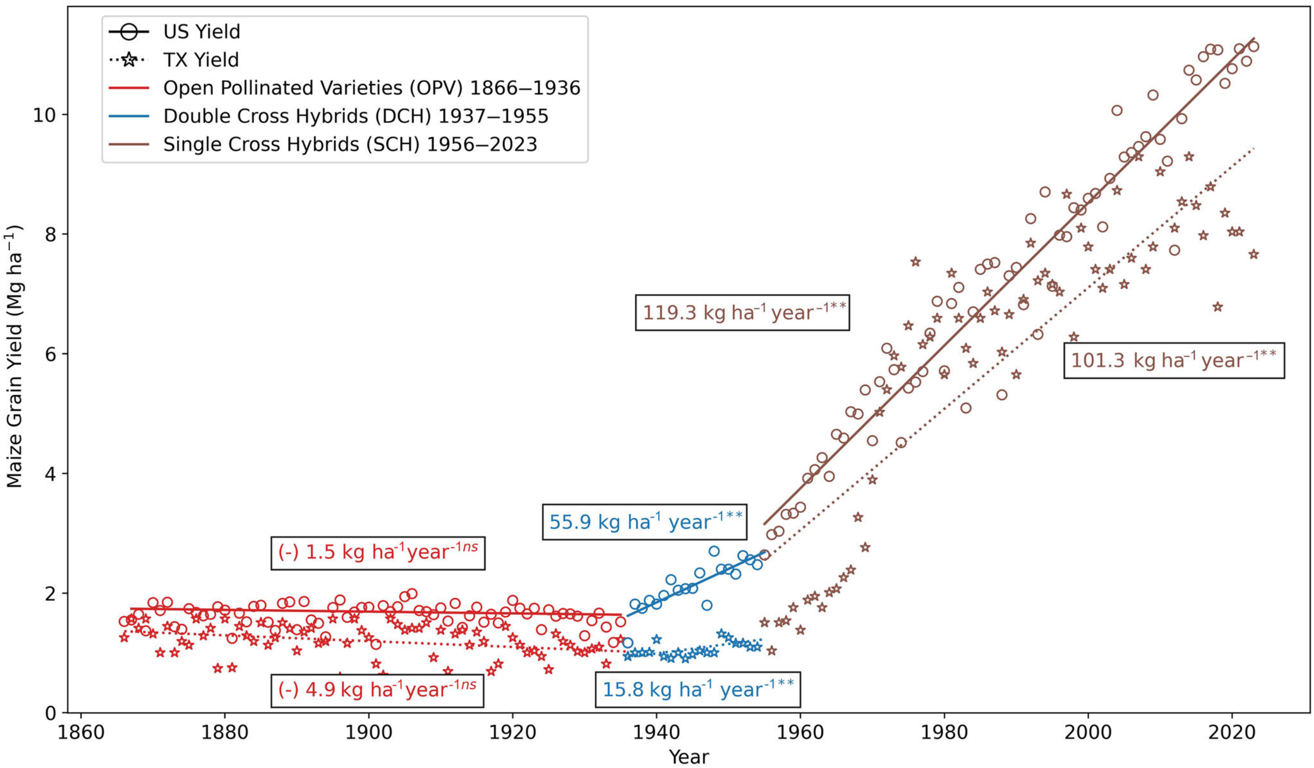

FIGURE 2 Historical average maize grain yield for the United States (circles) and Texas (stars) from 1866 to 2023. Solid lines and dotted lines represent the linear trend of the maize grain yields in three distinct periods of maize hybrids used by the producers. The number in the boxes represents a change in annual maize grain yield (kg per ha per year) in each era. *ns* = *p*-value more than 0.05 significance level, ***p*-value less than 0.05 significance level. *Source*: USDA–NAAS (2025).

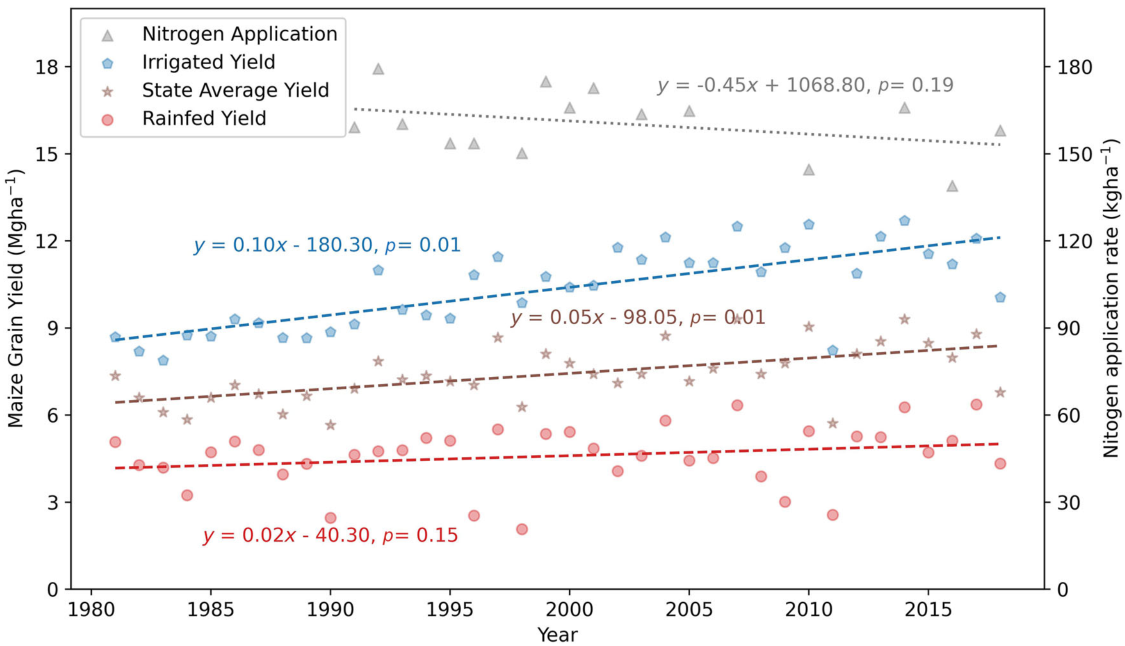

FIGURE 3 Trend of maize grain yield (left *Y*-axis) at state level under irrigated and rainfed conditions in Texas using the data from 1981 to 2018. Trend of the nitrogen application rate (right *Y*-axis) in Texas from 1991 to 2018. The color of the equations represents the same-colored linear lines. The equations represent the linear trends in each production condition along with their probability (*p*-value).

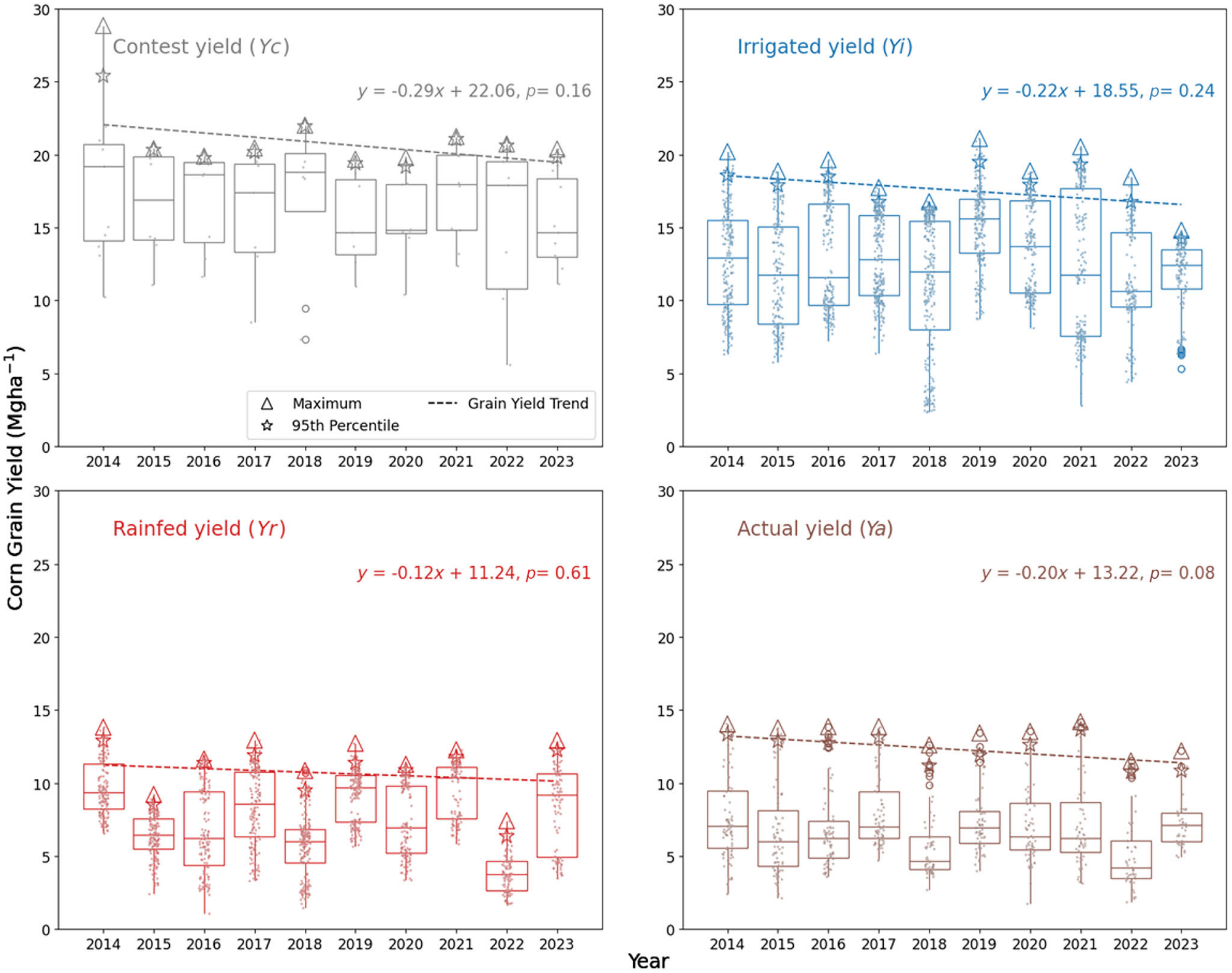

FIGURE 4 Maize grain yield trends in different production situations from 2014 to 2023 at Texas state level. The triangle represents the maximum yield and star represents 95th quantile yield. Maize grain yield trends based on the 95th quantile yield are represented. Top-left: contest yields; top-right: irrigated production situation; bottom-left: rainfed production situation; and bottom-right: actual yield situation. The equations represent the linear trends based on 95th quantile yield in each production condition (contest yield, irrigated yield, rainfed yield, and actual yield) along with their probability (*p*-value).

12.3 Mg ha^{-1}, indicating a substantial yield gap. The largest yield gap, *Yg1* (between *Yc* and *Ya*), was 40.87%, followed by *Yg2* (between *Yi* and *Ya*) at 30.11%. On the other hand, *Yg3* (between *Yr* and *Ya*) was found to be −13.0%, suggesting that actual yields exceeded the estimated water-limited yield at the state level. The trends for all these yield gaps, *Yg1*, *Yg2*, and *Yg3*, have remained stagnant over the past decade (Figure 5).

One possible explanation for this stagnation could be the limited genetic advancement in commercial maize hybrids used in Texas. The maize seed industry has largely centralized breeding efforts in the US Midwest, with less emphasis on developing hybrids tailored to Texas's diverse and often challenging environmental conditions (Barrero Farfan et al., 2013; Murray et al., 2019). Furthermore, the slower adaption of the high-density planting practices, commonly used in the Midwest, might have contributed to this yield stagnation (Djaman et al., 2022). These authors also enlisted the need of line and hybrid development programs to address region-specific growing conditions across Texas.

In most Texas regions outside the High Plains, maize is predominantly grown under rainfed conditions. Lack of irrigation is particularly common and challenging in the central and southern areas where extreme heat and drought events exacerbate crop stress. Such stresses can lead to poor grain filling and premature kernel abortion, ultimately reducing yield (Bheemanahalli et al., 2022). Enhancing maize productivity in these regions requires the development of genotypes with improved tolerance to heat and drought stress (Hao et al., 2015). Agronomic interventions, such as earlier planting dates to avoid summer heat and drought during grain filling, could also serve as viable strategies (Djaman et al., 2022). Increasing planting density has also shown some improvement in

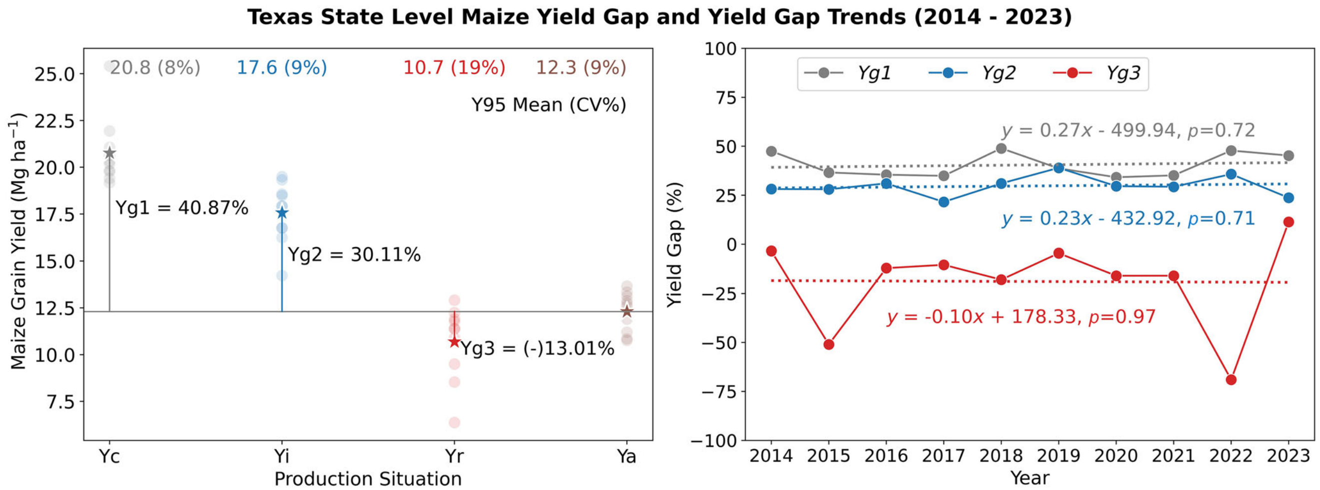

FIGURE 5 Left: state-level yield gap averaged for 10 years (2014–2023). Mean maize grain yield is the mean and 95th quantile yield at each production level (stars), and small, faded dots represent 95th quantile yield per year in those production situations. The horizontal gray line is the actual yield (*Ya*), whereas vertical lines indicate the yield gap in other production situations (*Yc* = contest yield, *Yi* = irrigated yield, *Yr* = rainfed yield) compared to *Ya*. On the top, mean 95th quantile value and coefficient of variation (CV%) are included for each production situation. *Yg1* = average yield gap between *Yc* and *Ya*; *Yg2* = average yield gap between *Yi* and *Ya*; *Yg3* = average yield gap between *Yr* and *Ya*. Right: state-level yield gap trends for *Yg1*, *Yg2*, and *Yg3* from 2014 to 2023. The equations represent the linear trends in each production condition along with their probability (*p*-value) to show associations between year and yield gap percentage.

maize yield in irrigated regions of the Texas (Bean & Gerik, 2005). However, the additional seed costs associated with higher plant populations often outweigh the modest yield benefits in water-limiting environments.

3.3 | Yield gap at agriculture district level

Texas encompasses diverse climatic regions and geographic variations, contributing to its complex agricultural landscape. Coastal areas in the south and southeast experience relatively higher precipitation, greater humidity, and warmer springs which favor early maize planting, as early as February in the Rio Grande Valley. This early maize planting also makes Texas unique within the national Genomes to Fields (G2F) study, as it is the only location where maize flowers while day length is increasing, a notable distinction given maize's photoperiod-sensitive ancestry (McFarland et al., 2020).

In contrast, northern and western regions of Texas are drier and cooler in spring, resulting in later planting dates, typically from April to June (Jiang et al., 2020). Maize production in central and southern Texas is predominately rainfed, while the northwest plains, characterized by arid conditions limited precipitation, rely heavily on irrigation from the Ogallala Aquifer for consistent and profitable maize grain production (Kimmel et al., 2016). However, the depleting aquifer levels pose significant challenges for sustaining irrigation-dependent maize production in this region (Chaudhuri & Ale, 2014; Kimmel et al., 2016). To counter the continuation of dried-up water wells, restrictions have now been placed on irrigation use in some counties (Musico, 2014).

Agricultural districts provide a good framework for evaluating regional contribution to maize production in Texas. Over the last decade, the North High Plains (NHP) alone contributed close to 46% of total maize grain yield (Mg) in Texas, followed by the Blacklands contributing about 19% and Upper Coast contributing about 12%. The South Central region also contributed about 5% of maize grain production in Texas in the last decade (Figure 1). The NHP also has the highest maize harvested area, around 20,000 ha annually, with an average grain yield of 11.4 Mg ha^{-1}. Although other agricultural districts, such as the Northern Low Plains, Southern High Plains, and Edwards Plateau, have higher average maize grain yields, their overall contributions to annual maize production in Texas were relatively smaller and hence were not a key focus beyond this point (Figure 1).

The average overall yield per acreage of maize was higher in the NHP district, followed by Upper Coast and then by South Central and Backlands. One key factor contributing to the superior yields in the NHP could be its lower average nighttime temperature throughout the maize-growing season (Figure S1). Elevated nighttime temperatures are known to accelerate respiration and phenological development, reducing sugar availability for kernel filling and shortening the grain-filling period, ultimately lowering kernel weight and yield (Badu-Apraku et al., 1983; Cantarero et al., 1999; Peters et al., 1971). Additionally, the NHP experiences lower relative humidity during the growth season, which, when combined

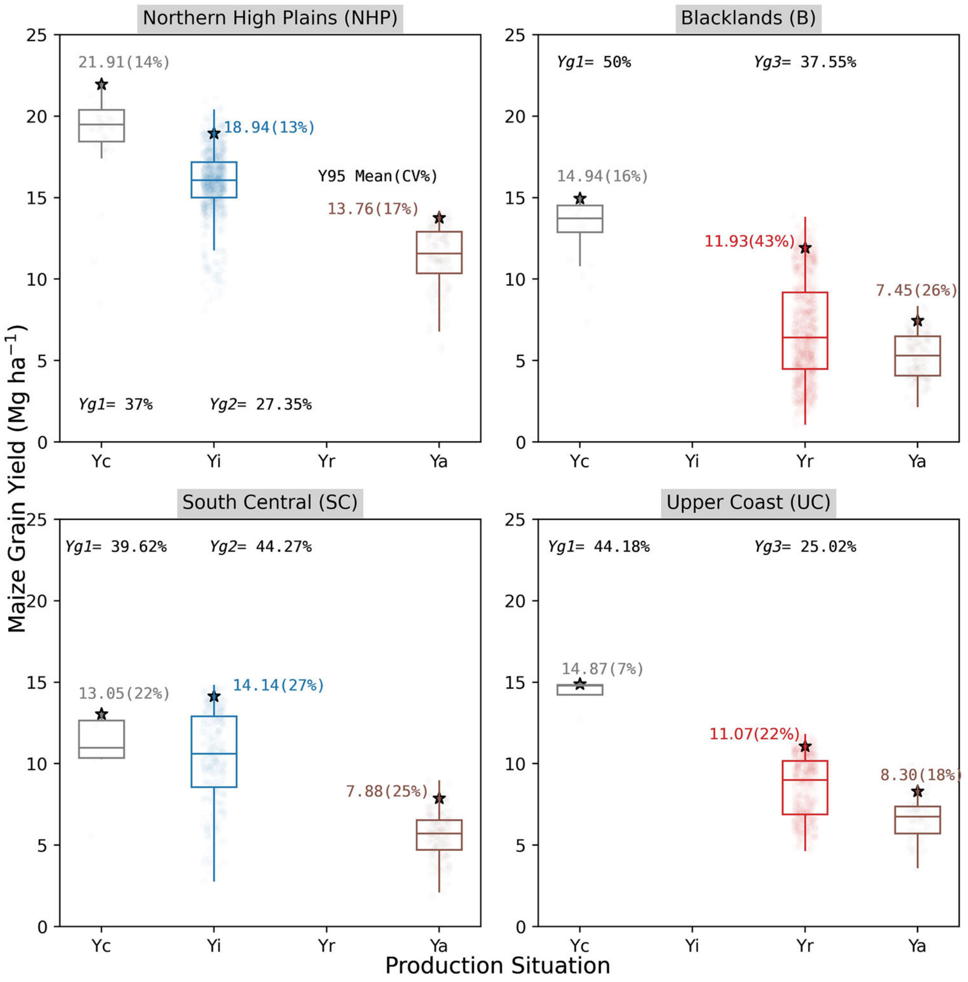

FIGURE 6 Comparison of agricultural district-level maize grain yield at each production situation for four agricultural districts (Northern High Plains, Blacklands, South Central, and Upper Coast). *Yc* = contest yield, *Yi* = irrigated yield, *Yr* = rainfed yield, *Ya* = actual yield. The star represents the 95th quantile mean grain yield in each production situation and is mentioned along with coefficient of variation (CV%). *Yg*1 = average yield gap between *Yc* and *Ya*; *Yg*2 = average yield gap between *Yi* and *Ya*; *Yg*3 = average yield gap between *Yr* and *Ya* from year 2014 to 2023.

with irrigation, supports higher planting densities and greater yield potential (Barrero Farfan et al., 2013; Bean & Gerik, 2005).

Over the past decade, the NHP accounted for an average of 21% of state's total maize harvested area. During the same period, the NHP region achieved an average actual yield (*Ya*) of 11.4 Mg ha^{-1} (standard deviation: 1.4 Mg ha^{-1}), compared to the combined average of 7.0 Mg ha^{-1} (standard deviation: 2.8 Mg ha^{-1}) across other maize-producing regions in Texas. Within the NHP, the maximum estimated *Yc* was 28.9 Mg ha^{-1}, *Yi* was 21.1 Mg ha^{-1}, and *Ya* was 14.2 Mg ha^{-1}. In terms of yield gaps, *Yg1* and *Yg2* for the NHP region were 37% and 27.4% when *Ya* was compared to *Yc* and *Yi*, respectively (Figure 6). Over the past decade, these yield gaps have remained statistically unchanged (Figure S2). The higher yield gaps (*Yg1* and *Yg2)* in the NHP appear to be driven by the practice of growing non-irrigated maize. Some producers have reduced irrigation due to water scarcity, cost concerns, or conservation efforts. This practice likely increases yield variability, as non-irrigated maize typically produces lower and more variable yields than irrigated maize. Since county-level yield estimates include both irrigated and non-irrigated fields, the inclusion of lower yielding rainfed maize could have reduced the overall average yield, thereby inflating the apparent yield gaps.

The Blacklands region, which extends from central Texas to the northern border (Figure 1), exhibited a *Yg1* of 58% and a *Yg3* (*Yr*–*Ya*) of 37.6%. Most maize in this region is grown under rainfed conditions, with limited adoption of irrigation. Some of the highest observed potential yield (*Yc*) may have been influenced by isolated irrigated fields, contributing to the large *Yg1*. Additionally, precipitation in the Blacklands is highly variable both spatially and temporally (Harmel et al., 2003). Some maize-producing locations receive ample precipitation during the growing season, supporting higher yields; while at the same time, other locations face extreme droughts, leading to lower yields. Few locations in this region are also affected by floods, limiting plant growth. This large spatial and interannual variability is reflected in the large cumulative variance (CV%) observed for both *Yr* (43%) and *Ya* (26%) (Figure 6). The trend in *Yg1* and *Yg3* has remained stagnant over time in this region, with greater interannual variability observed for *Yg3* (Figure S2).

In the South Central region, *Yg1* was 39.6%, and *Yg2* was 44.3% (Figure 6). The yield gap trends relative to *Ya* remained stagnant in this region as well (Figure S2). *Ya* primarily represents rainfed maize production in the region, as only a small number of producers utilize irrigation. However, variety testing trials conducted were irrigated only, which explains the absence of *Yr* and *Yg3* data for the South Central region. While the average *Yi* was found to be close to *Yc*, irrigation was not constantly applied, as noted in variety trial reports, leading to greater yield variability (CV: 27%) (Figure 6).

In the Upper Coast region, which lies close to the Gulf Coast region of the Atlantic Ocean, water availability is not a limiting factor in terms of quantity. However, high salinity levels limit the use of aquifer water for irrigation needed during flash drought periods (Barrero Farfan et al., 2013). Additionally, the region frequently experiences excessive rainfall, flooding, and poor drainage due to limited topographic slope, all of which hinder maize production. The *Yg1* was 44.2%, while *Yg3* was 25.0% (Figure 6). Notably, only 3 years of *Yc* data were available for this region, and those values, characterized by a low coefficient of variation (7%), likely originated from well-irrigated and well-drained fields during years with moderate precipitation. The yield gap trend *Yg3* in Upper Coast was also stagnant for the last decade (Figure S2).

4 | LIMITATIONS

This study utilized data from different production situations and diverse data sources, including the USDA–NASS survey, Texas A&M AgriLife hybrid testing multilocation trials, and NCGA contest results. However, each data source presented distinct challenges that may have influenced the interpretation of yield gap estimates. The USDA–NASS survey data, while comprehensive, are subject to uncertainties stemming from sampling errors, variability in management practices, and potential biases in data collection and processing. Additionally, this dataset may be disproportionately influenced by low-yielding counties or farms, which could have exaggerated the estimated yield gaps at the state level.

Hybrid testing trials, another key data source, are typically conducted on relatively small plots. These plots are prone to edge effects, where border plants receive more solar radiation and soil moisture than interior plants, potentially inflating yield estimates (Dhillon et al., 2022). Moreover, the trials may not fully represent the diversity of field conditions encountered in commercial production. Additionally, the analyses were constrained by unbalanced data at the agricultural district level, with missing data points across multiple years and regions, which limited the ability to conduct a comprehensive and consistent evaluation of maize production trends across all districts.

Contest yields (*Yc*), representing the highest realized attainable yields, were derived from a small number of high-performing entries, often reported by producers not evenly distributed across the state. These yields are typically selected from the best performing areas within a field and are influenced by multiple favorable factors. It is unlikely that uniform management practices alone could sustain such high yields across entire fields. Variability in soil properties, topography, and microclimate, factors not captured in contest data, would be reflected in broader county- or district-level averages. Furthermore, while some irrigated counties in the High Plains report higher average yields, the inclusion of lower yielding rainfed maize from central and southern Texas counties skews the statewide actual yield (*Ya*) downward. This aggregation effect may have contributed to an overestimation of the yield gap when comparing *Ya* to *Yc* or *Yi*.

5 | CONCLUSION

This study analyzed maize yield trends and yield gaps across Texas at both the state and agricultural district levels. Historical trends demonstrated that maize yields in the United States and Texas have increased significantly over the past century. However, yields and yield gaps in Texas have stagnated over the past decade. Actual state-level yields remained consistently below contest and irrigated yields, indicating persistent production constraints. At the district level, the rainfed Blacklands region experienced the largest yield gaps, mostly due to spatial and temporal rainfall variability, while the NHP, benefiting from irrigation and favorable temperatures, achieved the highest yields with comparatively smaller gaps.

Although the exact causes of current yield gaps remain unclear, potential contributing factors include climatic variability, limited region-specific research and hybrid development, and biophysical constraints (such as nutrient deficiencies, water stress, and soil heterogeneity), alongside socioeconomic challenges such as input costs and technology access. To address these issues and improve maize productivity, agronomic strategies such as adopting improved hybrids, optimizing nutrient and irrigation management, site-specific planting densities, timely planting, and weather-resilient crop rotations should be prioritized. Tailoring management practices to local conditions will be essential for maximizing yield potential and ensuring the long-term sustainability of maize production in Texas and other southern US states.

AUTHOR CONTRIBUTIONS

Bala Ram Sapkota: Conceptualization; formal analysis; investigation; methodology; software; visualization; writing—original draft. **Gurjinder S. Baath**: Conceptualization; funding acquisition; project administration; supervision; writing—review and editing. **Ronnie W. Schnell**: Data curation; methodology; writing—review and editing. **Jagmandeep S. Dhillon**: Methodology; writing—review and editing. **Seth C. Murray**: Writing—review and editing. **K. Colton Flynn**: Writing—review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Bala Ram Sapkota https://orcid.org/0000-0001-8915-5364
Gurjinder S. Baath https://orcid.org/0000-0002-3560-9866
Ronnie W. Schnell https://orcid.org/0000-0001-6174-9953
Jagmandeep S. Dhillon https://orcid.org/0000-0002-6260-5174
K. Colton Flynn https://orcid.org/0000-0002-5718-1071

REFERENCES

Badu-Apraku, B., Hunter, R. B., & Tollenaar, M. (1983). Effect of temperature during grain filling on whole plant and grain yield in maize (*Zea mays* L.). *Canadian Journal of Plant Science*, *63*(2), 357–363. https://doi.org/10.4141/cjps83-040

Barrero Farfan, I. D., Murray, S. C., Labar, S., & Pietsch, D. (2013). A multi-environment trial analysis shows slight grain yield improvement in Texas commercial maize. *Field Crops Research*, *149*, 167–176. https://doi.org/10.1016/j.fcr.2013.04.017

Bean, B., & Gerik, T. (2005). *Evaluating corn row spacing and plant population in the Texas Panhandle*. https://www.academia.edu/98455867/Evaluating_Corn_Row_Spacing_and_Plant_Population_in_theTexas_Panhandle

Bheemanahalli, R., Vennam, R. R., Ramamoorthy, P., & Reddy, K. R. (2022). Effects of post-flowering heat and drought stresses on physiology, yield, and quality in maize (*Zea mays* L.). *Plant Stress*, *6*, 100106. https://doi.org/10.1016/j.stress.2022.100106

Bockholt, A. J., & Collier, J. W. (1960). *Corn hybrids for Texas* (Bulletin No. 968). Texas Agricultural Experiment Station. https://babel.hathitrust.org/Corn-Hybrids-for-Texas

Butler, L. J., & Marion, B. W. (1984). Has the Plant Variety Protection Act achieved its legislative intent? *Journal of Agronomic Education*, *13*(2), 110–114. https://doi.org/10.2134/jae.1984.0110

Cantarero, M. G., Cirilo, A. G., & Andrade, F. H. (1999). Night temperature at silking affects set in maize. *Crop Science*, *39*(3), 703–710. https://doi.org/10.2135/cropsci1999.0011183x003900020017x

Chaudhuri, S., & Ale, S. (2014). Long term (1960–2010) trends in groundwater contamination and salinization in the Ogallala aquifer in Texas. *Journal of Hydrology*, *513*, 376–390. https://doi.org/10.1016/j.jhydrol.2014.03.033

Crow, J. F. (1998). 90 Years ago: The beginning of hybrid maize. *Genetics*, *148*(3), 923–928. https://doi.org/10.1093/genetics/148.3.923

Dhillon, J., Li, X., Bheemanahalli, R., & Reed, V. (2022). Mississippi state and county level yield gap in corn production. *Agricultural & Environmental Letters*, *7*(2), e20092. https://doi.org/10.1002/ael2.20092

Djaman, K., Allen, S., Djaman, D. S., Koudahe, K., Irmak, S., Puppala, N., Darapuneni, M. K., & Angadi, S. V. (2022). Planting date and plant density effects on maize growth, yield and water use efficiency. *Environmental Challenges*, *6*, 100417. https://doi.org/10.1016/j.envc.2021.100417

Duvick, D. N. (2005). The contribution of breeding to yield advances in maize (*Zea mays* L.). *Advances in Agronomy*, *86*, 83–145.

Duvick, D. N., & Cassman, K. G. (1999). Post–green revolution trends in yield potential of temperate maize in the north-central United States. *Crop Science*, *39*(6), 1622–1630. https://doi.org/10.2135/cropsci1999.3961622x

Egli, D. B., & Hatfield, J. L. (2014). Yield and yield gaps in central U.S. corn production systems. *Agronomy Journal*, *106*(6), 2248–2254. https://doi.org/10.2134/agronj14.0348

Food and Agriculture Organization of the United Nations. (2024). *FAOSTAT crops and livestock products*. https://www.fao.org/faostat/

Fischer, R. A. (2015). Definitions and determination of crop yield, yield gaps, and of rates of change. *Field Crops Research*, *182*, 9–18. https://doi.org/10.1016/j.fcr.2014.12.006

Frey, K. J. (1996). *National plant breeding study-I* (Special report 98). Iowa Agriculture and Home Economics Experimnent Station. https://www.nifa.usda.gov/sites/default/files/resource/National%20Plant%20Breeding%20Study-1.pdf

Fuglie, K. O. (2000). Trends in agricultural research expenditures in the United States. *Public-private collaboration in agricultural research* (pp. 9–22). Wiley.

Hao, B., Xue, Q., Marek, T. H., Jessup, K. E., Becker, J., Hou, X., Xu, W., Bynum, E. D., Bean, B. W., Colaizzi, P. D., & Howell, T. A. (2015). Water use and grain yield in drought-tolerant corn in the Texas High Plains. *Agronomy Journal*, *107*(5), 1922–1930. https://doi.org/10.2134/agronj15.0133

Harmel, R. D., King, K. W., Richardson, C. W., & Williams, J. R. (2003). Long-term precipitation analyses for the Central Texas Blackland Prairie. *Transactions of the ASAE*, *46*(5), 1381–1388. https://doi.org/10.13031/2013.15449

Hayes, H. K. (1956). I saw hybrid corn develop. In *Proceedings of the Annual Corn & Sorghum Industry Research Conference* (pp. 48–55). American Seed Trade Association.

Hunter, J. D. (2007). Matplotlib: A 2D graphics environment. *Computing in Science & Engineering*, *9*(3), 90–95. https://doi.org/10.1109/MCSE.2007.55

Jiang, W., Thapa, S., Jessup, K. E., Hao, B., Hou, X., Marek, T., Becker, J., Bell, J., & Xue, Q. (2020). Corn response to later than traditional planting dates in the Texas High Plains. *Crop Science*, *60*(2), 1004–1020. https://doi.org/10.1002/csc2.20042

Jordahl, K., Van den Bossche, J., Fleischmann, M., Wasserman, J., McBride, J., Gerard, J., Tratner, J., Perry, M., Badaracco, A. G., Farmer, C., Hjelle, G. A., Snow, A. D., Cochran, M., Gillies, S., Culbertson, L., Bartos, M., Eubank, N., maxalbert, Bilogur, A., … Leblanc, F. (2020). *geopandas/geopandas*. https://doi.org/10.5281/zenodo.3946761

Kimmel, T. M., Nielsen-Gammon, J., Rose, B., & Mogil, H. M. (2016). The weather and climate of Texas: A big state with big extremes. *Weatherwise*, *69*(5), 25–33. https://doi.org/10.1080/00431672.2016.1206446

Lobell, D. B., Cassman, K. G., & Field, C. B. (2009). Crop yield gaps: Their importance, magnitudes, and causes. *Annual Review of Environment and Resources*, *34*(1), 179–204. https://doi.org/10.1146/annurev.environ.041008.093740

McAfee, T. E., & Rogers, J. S. (1954). *Corn hybrids for Texas* (Bulletin No. 776). Texas Agricultural Experiment Station. https://catalog.hathitrust.org/Record/011469502

McFarland, B. A., AlKhalifah, N., Bohn, M., Bubert, J., Buckler, E. S., Ciampitti, I., Edwards, J., Ertl, D., Gage, J. L., Falcon, C. M., Flint-Garcia, S., Gore, M. A., Graham, C., Hirsch, C. N., Holland, J. B., Hood, E., Hooker, D., Jarquin, D., Kaeppler, S. M., … de Leon, N. (2020). Maize genomes to fields (G2F): 2014–2017 field seasons: Genotype, phenotype, climatic, soil, and inbred ear image datasets. *BMC Research Notes*, *13*(1), 71. https://doi.org/10.1186/s13104-020-4922-8

McKinney, W. (2010). *Data structures for statistical computing in Python*. SciPy. https://doi.org/10.25080/Majora-92bf1922-00a

Murray, S. C., Mayfield, K., Pekar, J., Brown, P., Lorenz, A., Isakeit, T., Odvody, G., Xu, W., & Betran, J. (2019). Tx741, Tx777, Tx779, Tx780, and tx782 inbred maize lines for yield and southern United States stress adaptation. *Journal of Plant Registrations*, *13*(2), 258–269. https://doi.org/10.3198/jpr2017.07.0044crp

Musico, J. (2014). Some do, don't—Metering, restrictions vary among Texas water districts. *Lubbock Avalanche-Journal*. https://www.lubbockonline.com/some-do-dont-metering-restrictions-among-Texas-water-districts

National Corn Growers Association. (2024). *Annual yield contest*. https://ncga.com/get-involved/national-corn-yield-contest

Patrignani, A., Lollato, R. P., Ochsner, T. E., Godsey, C. B., & Edwards, J. T. (2014). Yield gap and production gap of rainfed winter wheat in the southern Great Plains. *Agronomy Journal*, *106*(4), 1329–1339. https://doi.org/10.2134/agronj14.0011

Peters, D. B., Pendleton, J. W., Hageman, R. H., & Brown, C. M. (1971). Effect of night air temperature on grain yield of corn, wheat, and soybeans. *Agronomy Journal*, *63*(5), 809–809. https://doi.org/10.2134/agronj1971.00021962006300050046x

Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C., & Foley, J. A. (2012). Recent patterns of crop yield growth and stagnation. *Nature Communications*, *3*(1), 1293. https://doi.org/10.1038/ncomms2296

Ritchie, H., Rosado, P., & Roser, M. (2025). *Agricultural production*. Our World in Data. https://ourworldindata.org/agricultural-production

Schimmelpfennig, D. E., Pray, C. E., & Brennan, M. F. (2004). The impact of seed industry concentration on innovation: A study of US biotech market leaders. *Agricultural Economics*, *30*(2), 157–167. https://doi.org/10.1111/j.1574-0862.2004.tb00184.x

Schnell, R., Horn, K., Fontana, G., Hanes, J., & Murray, S. (2024). *Texas corn performance variety trials*. Texas A&M University, Department of Soil and Crop Sciences. https://varietytesting.tamu.edu/corn/

Sexton-Bowser, S., & Patrignani, A. (2024). Yield gap analysis for rainfed grain sorghum in Kansas. *Agronomy Journal*, *116*(6), 2901–2911. https://doi.org/10.1002/agj2.21684

Troyer, A. F. (1996). Breeding widely adapted, popular maize hybrids. *Euphytica*, *92*(1), 163–174.

Troyer, A. F. (1999). Background of U.S. hybrid corn. *Crop Science*, *39*(3), 601–626. https://doi.org/10.2135/cropsci1999.0011183x003900020001xa

Troyer, A. F. (2009). Development of hybrid corn and the seed corn industry. *Handbook of maize* (pp. 87–114). Springer New York.

United States Department of Agriculture–National Agricultural Statistics Service. (2025). *Corn, grain—Production*. Quick Stats. https://quickstats.nass.usda.gov/

van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P., & Hochman, Z. (2013). Yield gap analysis with local to global relevance—A review. *Field Crops Research*, *143*, 4–17. https://doi.org/10.1016/j.fcr.2012.09.009

van Wart, J., Kersebaum, K. C., Peng, S., Milner, M., & Cassman, K. G. (2013). Estimating crop yield potential at regional to national scales. *Field Crops Research*, *143*, 34–43. https://doi.org/10.1016/j.fcr.2012.11.018

Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., van der Walt, S. J., Brett, M., Wilson, J., Millman, K. J., Mayorov, N., Nelson, A. R. J., Jones, E., Kern, R., Larson, E., … Vázquez-Baeza, Y. (2020). SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods*, *17*(3), 261–272. https://doi.org/10.1038/s41592-019-0686-2

Waskom, M., Botvinnik, O., O'Kane, D., Hobson, P., Lukauskas, S., Gemperline, D. C., Augspurger, T., Halchenko, Y., Cole, J. B., Warmenhoven, J., Ruiter, J., Pye, C., Hoyer, S., Vanderplas, J., Villalba, S., Kunter, G., Quintero, E., Bachant, P., Martin, M., … Qalieh, A. (2017). *mwaskom/seaborn: v0.8.1 (September 2017)*. https://doi.org/10.5281/zenodo.883859

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Sapkota, B. R., Baath, G. S., Schnell, R. W., Dhillon, J. S., Murray, S. C., & Flynn, K. C. (2026). Yield gap analytics in maize production for Texas agricultural district and state levels. *Agronomy Journal*, *118*, e70454. https://doi.org/10.1002/agj2.70454