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Climate Change and Extreme Weather Effects on Nebraska Corn Production: Differential Responses in Irrigated and Non-irrigated Systems

Manning Xu

Beijing Haidian Foreign Language Academy, Beijing, China
xumanning12345@gmail.com

Abstract. This study investigated the effects of climate change-driven extreme weather in July, especially drought, on corn yields in Nebraska. The yields of irrigated and non-irrigated (rainfed) corn were compared using data over 20 years, from 1998 to 2018, to see the effect of irrigation on reducing crop losses during the drought period. Simple linear regression models were applied to examine relationships between crop yield and precipitation in July and the Palmer Drought Severity Index (PDSI). As a result, rainfed corn showed clear sensitivity to July weather conditions, with yields dropping sharply in dry years and varying between years. However, irrigated corn remained stable and wasn't largely affected by either drought or rainfall levels. Overall, the study suggested that sustainable irrigation could reduce yield sensitivity to July moisture stress, resulting in higher mean yields and resistance to weather change. The findings suggest that irrigation is an effective way to protect corn production against warmer summer weather, while over-depleting groundwater sources like the Ogallala Aquifer would negatively affect future sustainability. Therefore, adaptive water management will be important for maintaining reliable corn output under a changing climate.

Keywords: climate change, drought, corn yield, irrigation, Nebraska

1. Introduction

Climate change, caused by greenhouse gas emissions, has become a critical global issue and poses significant challenges to agricultural production by increasing the frequency and intensity of extreme weather events and rising temperatures. Recently, researchers discovered a strengthening relationship between the maximum temperature and drought severity, leading to decreased crop yield, increased food prices, and potential food insecurity [1, 2].

Corn, as one of the most important staple crops worldwide, plays a crucial role in global food systems. Moreover, corn is being used as a feed grain, and accounts for more than 95 percent of total feed grain production and use [3]. In addition, corn is a key ingredient for ethanol production [3].. However, corn is highly sensitive to climatic stressors such as drought and temperature extremes, particularly during the reproductive stage [4].

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Nebraska, a state located in the U.S. Corn Belt, ranked third in corn production and second in the production of ethanol in the US [1]. Corn production in Nebraska can be broadly categorized into rainfed, or non-irrigated, and irrigated ones; most of the water for irrigation comes from the Ogallala Aquifer. According to the University of Nebraska, irrigated corn in Nebraska yields an average of about 200 bushels per acre, whereas non-irrigated corn averages approximately 147 bushels per acre [5]. However, these lands are being affected by the changing climate, water demand is increasing with rising temperatures, while water availability is becoming increasingly limited, which means more summers are likely to become increasingly hot and dry, which reduces yields of some crops [6].

Therefore, this study aims to examine the impacts of drought and precipitation variability on corn yield in Nebraska and to compare the responses of irrigated and non-irrigated corn systems. It is hypothesized that rainfed corn, or non-irrigated corn, is more sensitive to drought conditions, whereas irrigation mitigates the climate effect and stabilizes the annual production.

2. Literature review

Previous studies have focused on the effect of climate change on a wider range of places, such as the whole Great Plains, while this study focuses on a specific state, Nebraska, which allows this study to better capture state-specific conditions. For example, factors like irrigated and non-irrigated can be included and therefore provide more available and realistic suggestions or solutions [7]. Also, many studies have focused on how extreme weather caused by climate change affects crop growth, but this study focused on corn, which is one of the most important crops worldwide, and can be used for either eating, feeding, or ethanol production [8, 9].

On the other hand The study focuses on the drought index and precipitation in July for each year. Previous studies have identified July precipitation as the most influential climatic factor affecting U.S. corn yields, followed by July temperature and planting date [9]. July precipitation has been described as a "golden number" due to its strong and consistent relationship with yield variability [10].

3. Methodology

3.1. Data sources

This study analyzed 20 years of production, from 1998 to 2018. The period from 1998 to 2018 represents a contemporary phase of climate change, including increasing climate variability and intensified extreme weather [11]. Those factors make this period particularly relevant for assessing climate impacts on modern agricultural systems.

This study aimed to observe how drought and precipitation affect corn yield in Nebraska. Therefore, to achieve this goal, several pieces of data are required.

3.1.1. Corn yield data

The corn yield, in bushels, was being calculated by the formula:

$$\frac{\text{Total value}}{\text{Acres}}$$

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Corn yield (bushels per acre) was calculated as the ratio of total production to harvested area for both irrigated and non-irrigated corn. Annual state-level yield data for Nebraska from 1998 to 2018 were obtained from the USDA National Agricultural Statistics Service (NASS), Nebraska Field Office.

3.1.2. Drought index

PDSI, the Palmer Drought Severity Index, integrates precipitation, temperature, and soil moisture balance. Positive values indicate wet or normal conditions, while negative values indicate drought, with lower values representing more severe drought PDSI is used in this study to represent the drought level in Nebraska over the 20 years. PSDI is a standardized index that ranges between -10 (dry) and +10 (wet). The index is effective for assessing long-term drought conditions, particularly in low and mid-latitude regions. Also, it incorporates surface air temperature and a physical water balance model to account for the effects of global warming through potential evapotranspiration [12].

3.1.3. Precipitation

The precipitation data for July over the 20 years were provided by the National Centers for Environmental Information from the National Oceanic and Atmospheric Administration (NOAA). The data was being measured in inches, and this data directly shows the relationship between corn yield and water supply, which shows the importance of irrigation.

3.2. Data processing and analysis methods

Corn yield was treated as the dependent variable, while July precipitation and PDSI were treated as independent variables. Pearson correlation coefficients were calculated to examine the relationships between yield and climate variables. Linear regression models were used to quantify the influence of precipitation and drought conditions on corn yield. The coefficient of determination (R^2) was calculated to assess the proportion of yield variability explained by the climate variables.

Separate regression analyses were conducted for irrigated and non-irrigated corn to compare their relative sensitivity to climate variability. Scatter plots with fitted regression lines were generated to visualize the relationships between climate factors and yield. All statistical analyses and visualizations were performed using R software.

4. Results

Figure 1 indicated the annual corn yield for irrigated and non-irrigated corns from 1998 to 2018. Irrigated corn generally produced higher yields than non-irrigated corn throughout the study period. The average yield was 180.4 bushels per acre for irrigated corn and 114.7 bushels per acre for non-irrigated corn.

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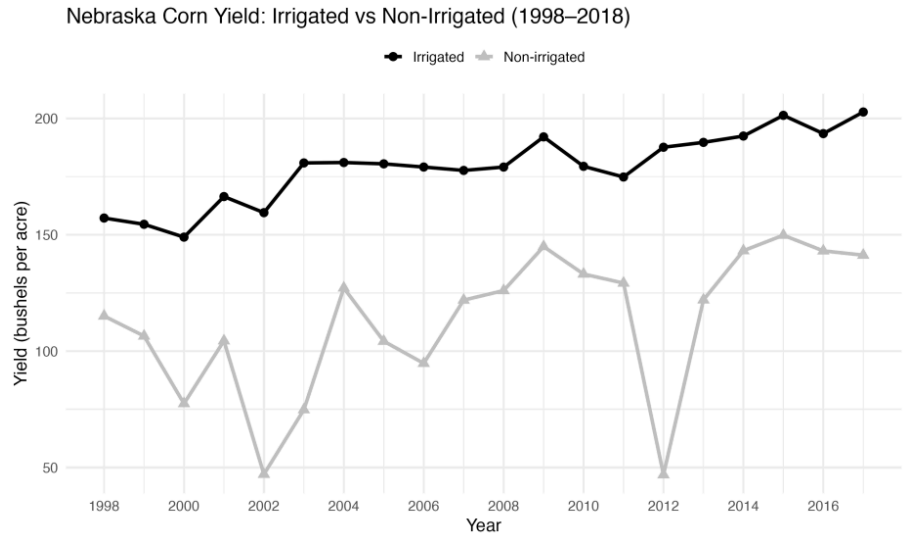

Figure 1. Irrigated and non-irrigated corn yield between 1998 and 2018

In addition to the difference in average yield, non-irrigated corn showed more variation from year to year compared to irrigated corn. Yield changes were larger in rainfed systems, while irrigated yield remained relatively stable over the study period.

To further examine the relationship between climate variables and yield, linear regression analyses were conducted separately for irrigated and non-irrigated corn using July precipitation and PDSI as independent variables.

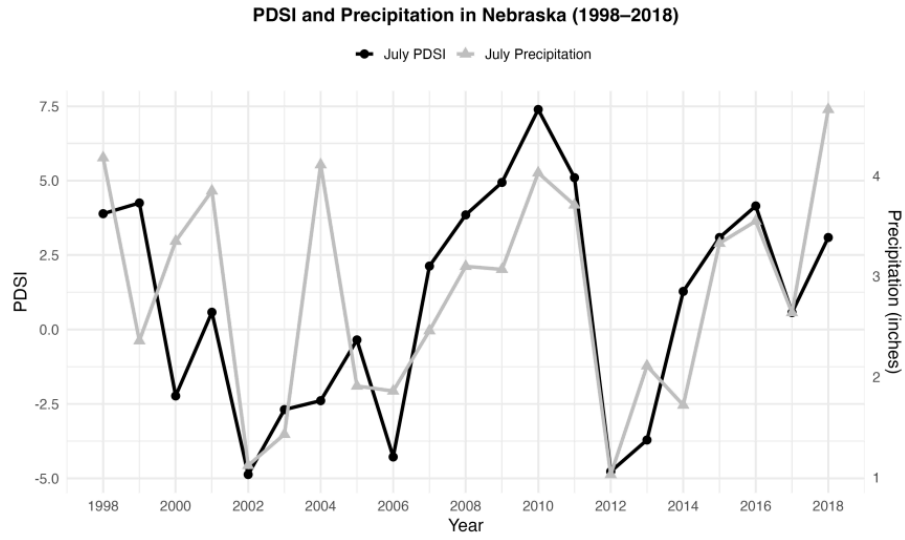

Figure 2. PDSI and precipitation in July from 1998-2018

Figure 2 showed the relationship between PDSI and precipitation. From 1998 to 2018, July PDSI values in Nebraska show high interannual variability rather than a clear linear trend. Extreme drought conditions occurred in 2002 and 2012, while 2010 marked an exceptionally wet year. Although precipitation generally followed similar patterns, difference between precipitation and PDSI values suggest that temperature-driven evapotranspiration and antecedent moisture conditions influenced drought severity [12].

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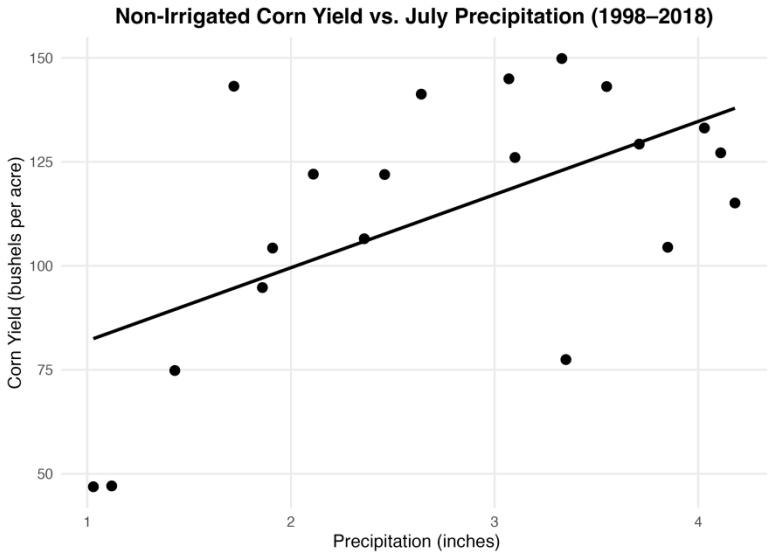

Figure 3. Linear regression of non-irrigated corn yield on July precipitation in Nebraska, 1998–2018 ($R^2 = 0.337$)

Figure 3 illustrates the relationship between rainfed corn yield and precipitation in July in Nebraska from 1998 to 2018. This equation indicated the linear regression for yield:

$$\text{Yield} = 17.588 \times \text{precip (in)} + 64.358$$

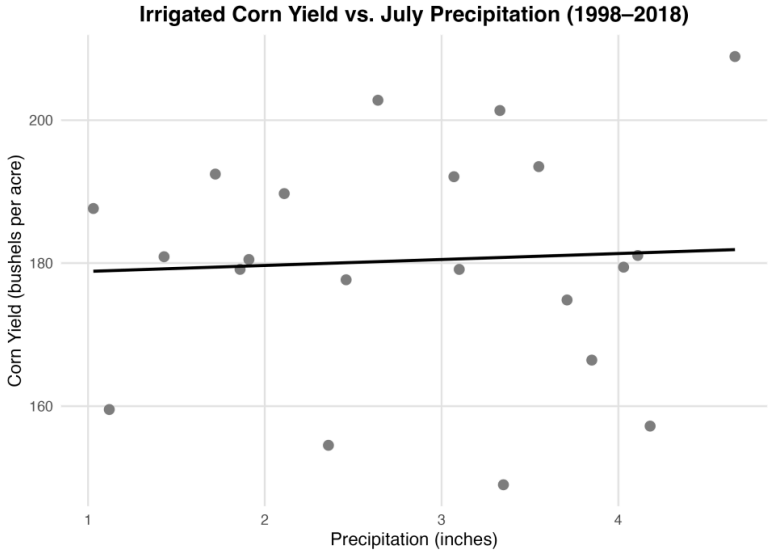

Figure 4. Linear regression of irrigated corn yield on July precipitation in Nebraska, 1998–2018 ($R^2 = 0.003$)

The R^2 value was 0.337, which indicated a statistically positive but moderately weak association. To be more specific, approximately 33.7% of the interannual variability in rainfed corn yield can be explained by July precipitation. Furthermore, each additional inch of precipitation was associated with an estimated 17.6 bu/ac increase in yield. However, there will be several other factors that

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influence crop yield, such as soil moisture and nutrient management. Notably, yields remain highly variable even at moderate to high precipitation levels (>3 inches), and several low-yield outliers occur under very low precipitation (<1.5 inches), highlighting the vulnerability of rainfed corn to drought during the critical reproductive growth stages, which normally occur in July.

According to figure 4, this scatter plot showed the relationship between irrigated corn yield and July precipitation in Nebraska from 1998 to 2018. The fitted simple linear regression is extremely flat, with the equation :

$$\text{Yield} = 0.832 \times \text{Precip (in)} + 178.011$$

The $R^2 = 0.003$; this near-zero R^2 value indicated that July precipitation explained nearly none of the variation in irrigated corn yields over the years. Yields cluster tightly between roughly 160 and 210 bu/ac, with the large majority falling in the 175 - 200 bu/ac range regardless of whether July precipitation was 1 inch or over 4 inches. This pattern demonstrated that irrigation effectively decouples corn yield from natural rainfall in July. Once water stress is removed through supplemental irrigation, water was no longer a limiting factor during the critical reproductive period, and yield was instead determined primarily by other factors.

The most striking contrast between Figures 4 and 5 was the dramatically different dependence of corn yield on July precipitation under irrigated versus rainfed conditions. For irrigated corn, the relationship is virtually nonexistent, with a near-zero R^2. The yields were stably high and largely insensitive to July rainfall amount, which was evidence that irrigation removes the limitation of water during the growing season. In contrast, rainfed corn exhibited a moderately strong positive linear relationship, meaning July precipitation alone accounts for about one-third of yield variability. Years with low precipitation (<1.5–2 inches) frequently produce severe yield collapses in rainfed systems, whereas the same drought conditions have almost no detectable effect on irrigated fields. Even at moderate to high precipitation levels, rainfed corns remain far more variable and generally lower than their irrigated counterparts. Collectively, these patterns highlight irrigation's powerful risk-reduction role by transforming July precipitation from a major yield-determining factor into an almost irrelevant variable, making the corns more resistant to climate change.

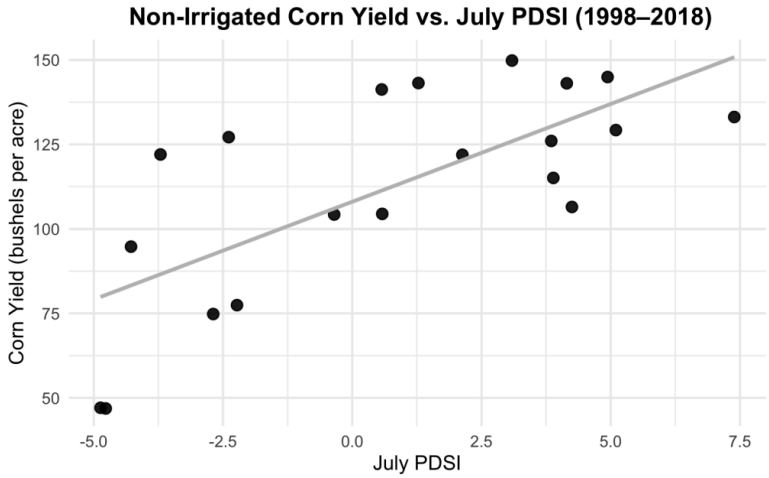

Figure 5. Linear regression of non-irrigated corn yield on July PDSI in Nebraska, 1998–2018 (R^2 = 0.499)

DOI: 10.54254/2754-1169/2026.GT37629

The linear regression equation for the model in Figure 5 is:

$$\text{Yield} = 5{,}786 \times \text{PDSI} + 108.046$$

With R2 = 0.499, July PDSI alone explained nearly 50% of the year-to-year variation in rainfed corn yields, which is noticeably stronger than the relationship with July precipitation alone (R2 = 0.337). This confirmed that PDSI, as a composite measure of moisture stress, captures rainfed corn's response to water conditions more effectively than precipitation volume by itself.

The points revealed a strong positive trend. In severely dry Julys with PDSI around -5 to -3, yields often collapse to 50 - 80 bu/ac, highlighting the catastrophic effect of water deficits during the critical reproductive stages. As PDSI moves toward and above 0, yields steadily increase into the 120 - 150+ bu/ac range. Even in very wet conditions with PDSI > 5, some scatter exists, but the overall direction is upward. Compared to raw precipitation, PDSI better accounts for temperature-driven evapotranspiration and soil moisture depletion, which explains why it performs better at distinguishing extreme low-yield years from moderate-to-high yield years.

In summary, for rainfed corn production in Nebraska, the integrated intensity of moisture stress in July is one of the dominant drivers of yield variability, and PDSI is an effective indicator for capturing that stress.

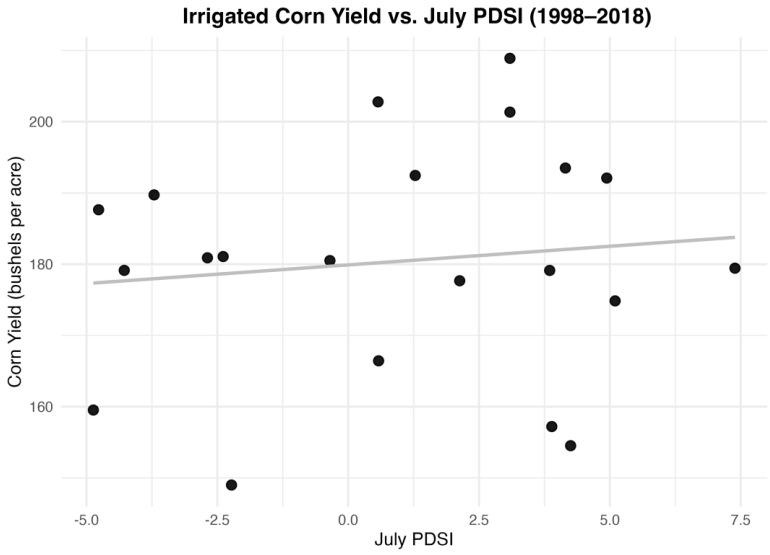

Figure 6. Linear regression of irrigated corn yield on July PDSI in Nebraska, 1998–2018 (R^2 = 0.014)

This scatter plot shows the relationship between irrigated corn yield and July PDSI in Nebraska from 1998 to 2018.

The linear regression equation for Figure 6 is:

$$\text{Yield} = 0.523 \times \text{PDSI} + 17.899$$

With R^2 = 0.014, July PDSI explains just 1.4% of the year-to-year variation in irrigated corn yields, indicating that there is almost no relationship between PDSI and irrigated corn yield.

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The data points were widely scattered and didn't show a clear linear trend. Yields are concentrated mainly between 170 and 210 bushels per acre. There was no systematic yield decline during very dry Julys, nor any consistent increase during wet Julys. This pattern confirms that irrigation effectively removes natural July moisture stress as a limiting factor during the critical reproductive stages. Yield variation under irrigation was therefore driven primarily by other environmental or artificial factors.

The difference in response to July PDSI between irrigated and non-irrigated corn is clear. In the rainfed system, there is a moderately strong positive relationship, with yields collapsing to 50 to 80 bu/ac in severe drought years and rising well above 140 bu/ac in wet years, showing that rainfed corn is highly sensitive to July's moisture conditions.

In contrast, irrigated corn shows almost no sensitivity to drought, with yields remaining relatively stable regardless of whether July was extremely dry or very wet. The same drought conditions that devastate rain-fed fields have virtually no detectable impact on irrigated fields.

In summary, rainfed corn remains strongly tied to July moisture conditions, with PDSI explaining nearly half of yield variability, while irrigated corn is almost completely insulated from it, delivering much higher and far more consistent yields. This highlights the substantial advantage of irrigation in reducing drought-related risk in regions like Nebraska.

5. Discussion

The findings highlight the clear advantage of irrigation in buffering corn yields against July drought and precipitation variability in Nebraska. Rainfed corn showed moderate to strong sensitivity to July precipitation and especially to PDSI, with yields often collapsing to 50–80 bu/ac in severe dry years and rising markedly in wetter conditions. Irrigated corn, by contrast, exhibited almost no response, maintaining stable yields around 180 bu/ac regardless of July moisture stress. This confirms that irrigation effectively eliminates natural water limitations during critical reproductive stages, resulting in higher average yields and greatly reduced year-to-year volatility. These results support the hypothesis that non-irrigated corn is far more vulnerable to drought, while irrigation provides strong risk mitigation and production stability.

However, there are some limitations to irrigation. Most Nebraska irrigation relies on the Ogallala Aquifer, which has experienced long-term depletion in many areas due to heavy pumping exceeding recharge rates and facing the problem of the tragedy of the commons [13]. As climate change intensifies evapotranspiration and dry periods, water demand will likely rise further, accelerating aquifer decline and increasing pumping costs. Energy prices, infrastructure maintenance, and access to groundwater also impose economic burdens, particularly for smaller farms or fields with deeper water tables. Over-reliance on irrigation could therefore become unsustainable in the long run without careful management.

6. Conclusion

This study shows that irrigation strongly buffers Nebraska corn yields against July drought and precipitation variability. Non-irrigated corn responded noticeably to July precipitation and especially to PDSI, with sharp yield drops in dry years and much more year-to-year fluctuation. Irrigated corn showed almost no response, staying steady around 180 bu/ac no matter the July conditions. Overall, irrigation delivered higher average yields and far less risk compared to rainfed systems.

These patterns matter because they suggest irrigation can help keep corn production reliable as climate change brings more hot, dry summers. Nebraska's corn supports both feeding and ethanol

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production, so stabilizing yields protects those supply chains.

At the same time, most irrigation depends on the Ogallala Aquifer, which is already losing water in many places since water pumping outpaces natural recharge. If depletion continues, water price will rise, and irrigation systems might be less affordable for farmers.

However, the study had several limitations. It uses statewide averages and looks only at weather in July, so it might not represent specific conditions in every city. Statistical significance was not formally tested; therefore, results should be interpreted as descriptive associations rather than confirmed causal relationships. The 1998-2018 period captures recent trends but may not reflect more extreme future conditions.

For future studies, researchers could use climate models to predict how worsening drought might change the yield gap in coming decades. In order to ease pressure on the aquifer, future work should also explore alternatives like rainwater collection. Developing such an approach could help maintain good yields while using groundwater more sustainably and building longer-term resilience for Nebraska agriculture.

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