Improving Resilience of Corn to Weather through Improved Fertilizer Efficiency

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Summary
Fertilization is a critical management tool to improve crop productivity. Corn requires more N fertilizer than some other crops, but the fertility needs of the crop vary based on the growing environment. In this study, we used a modeling approach to examine the historical record and delineate the interaction between fertilizer and weather on the sensitivity of corn yield to climate in southeastern Kansas. Providing optimal fertilizer can improve corn yield. However, too much fertilizer can be expensive and wasteful. This study demonstrated that the climate resilience of corn is moderated by how much fertilizer is applied. The model results concluded that the optimal N fertilizer rate should be adjusted based on weather conditions.

Introduction
The addition of fertilizer has long been recognized as a key factor to increase the yield of crops. However, rising fertilizer costs have led to exploration of other methods of maintaining high crop yield, while reducing economic costs and negative environmental impacts.

Corn acreage in Kansas has been steadily increasing. Corn has the potential to yield well in southeast Kansas, but can be limited by hot, dry growing conditions, especially near anthesis. Corn also requires substantial inputs of artificial fertilizers for optimal productivity, increasing production costs and risk. Crop growth and development can be modeled by calculating the growing degree days (GDD). Additional information on potential crop growth and performance can be obtained by calculating Extreme Degree Days (EDD). The EDD are a measure of the impact of high damaging temperatures on crop growth and yield.

This study was conducted to explore the interaction between nitrogen fertility in corn and the growing environment. The research used a modeling approach to examine historical data trends and delineate nitrogen fertility strategies to optimize crop yield at reduced costs.

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Experimental Procedures

The research focused on the 14 counties in southeast Kansas. The county-level corn yield data were collected from the U.S. Department of Agriculture National Agricultural Statistics Service census dataset (*https://www.nass.usda.gov/*). Corn-specific nitrogen fertilizer use for each county was obtained from a published dataset (Zhang et al., 2021). Daily weather data were collected from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; Daly et al., 2008). Growing-degree days were calculated from daily maximum and minimum temperature, and represented the heat accumulated between the base of 50°F and the maximum 86°F during the corn growing season ($GDD = (T_{max} + T_{min})/2$). Extreme-degree days during the growing season were calculated from the daily maximum temperature. The EDD represented the accumulation of high temperatures above 86°F and is calculated as: $EDD = T_{max} - T_{upper}$ for maximum daily temperatures that exceeded the upper temperature of 86°F. Temperatures above 86°F reduce corn growth and development.

To delineate the interaction of corn fertilizer with climate, we developed a series of fixed-effect models using the historical data from the fourteen counties in southeast Kansas. The models accounted for factors that influenced corn growth and yield development, and included GDD, EDD, precipitation, and nitrogen fertilizer applied.

Results and Discussion

The 2012 growing season was the hottest year with highest cumulative extreme degree days over the past 12 years (Figure 1). The hot and dry conditions experienced during 2012 led to the lowest corn yield in the past 30 years (Sassenrath et al., 2023). The fixed-effect path analysis models delineated how each of the environmental factors impacted corn grain production over the past 39 years (1981–2019). The integrated contribution of GDD, EDD, and precipitation to corn yield impacted the yield with a change from a cumulative reduction of 3.5% (Greenwood) to an increase of 11% (Labette) in the counties in southeastern Kansas (Figure 2), with each county experiencing different impacts of each climatic variable. Increased precipitation always benefited corn yield, especially in Labette County (4.6%). The changes in EDD had a greater impact on corn yield than did the change in GDD. Corn yield increased with higher GDD in all counties. While corn yield benefited from more heat units (higher GDD), excessive temperatures (high EDD) reduced yield. Increasing EDD reduced the corn yield (-0.7% to ~ -4.8%) in 6 counties. The remaining eight counties saw a decrease in EDD over the 31-year study period, with a gain in corn yield.

To determine the interaction of N fertilizer and environment, historical data were separated into six scenarios of three temperatures (cold, normal, or warm) and three precipitation ranges (dry, normal, and wet). Optimal N fertility rates were determined from the models based on the historical yield trends under the different environmental conditions. Optimal N rate decreased with greater EDD for all precipitation levels (Figure 3). There were three conditions with inadequate data, so no N rates were obtained (warm temperatures, low EDD under dry and normal precipitation, cold temperatures, high EDD, and wet conditions). As precipitation increased, the crop would be able to use higher rates of N. Corn yield was positively sensitive to more precipitation and higher N fertilizer use could enhance the positive sensitivity. Hence, corn yield could benefit from greater N application in a wet climate. However, under hotter years (higher EDD) higher N application led to a yield decline. Therefore, less N should be applied in hot years (high EDD) to reduce the harm of extremely high temperatures on corn yield. The N application should be adjusted based on climate conditions to improve the utilization of N and reduce economic costs. The optimal N fertilizer rate increased with increasing precipitation. Under wet conditions, the optimal N fertilizer rate ranged from 207 lb N/acre to 338 lb N/acre. The optimal N fertilizer rate increased with higher GDD but decreased with higher EDD. In summary, higher rates of N fertilizer will be more beneficial to corn yield in wet (more precipitation) and warm (higher GDD) years. Under dry (less precipitation) and hotter (high EDD) climates, the N application should not be more than 120 lb N/acre. Under the average environmental conditions, the amount of optimal N application increased from west to east in southeastern Kansas, with the highest optimal N application of 166 lb N/acre in Cherokee County (Figure 4).

Conclusions

Application of fertilizer is an important tool to increase crop yields. Previously, fertilizer was an inexpensive tool to reduce the risks of crop production. However, with the increasing costs of fertilizers, it is important to manage fertilizers for best economic return. In addition to being expensive, excess N that is not used by plants can be lost to waterways or to the atmosphere. In wet years (higher precipitation), corn is able to better utilize the applied nitrogen. Warmer temperatures (higher GDD) increase corn growth and production, and hence corn can utilize more applied N. However, in very hot years (high EDD), excess application of N decreases yield, and lower rates of applied N are more beneficial.

Acknowledgments

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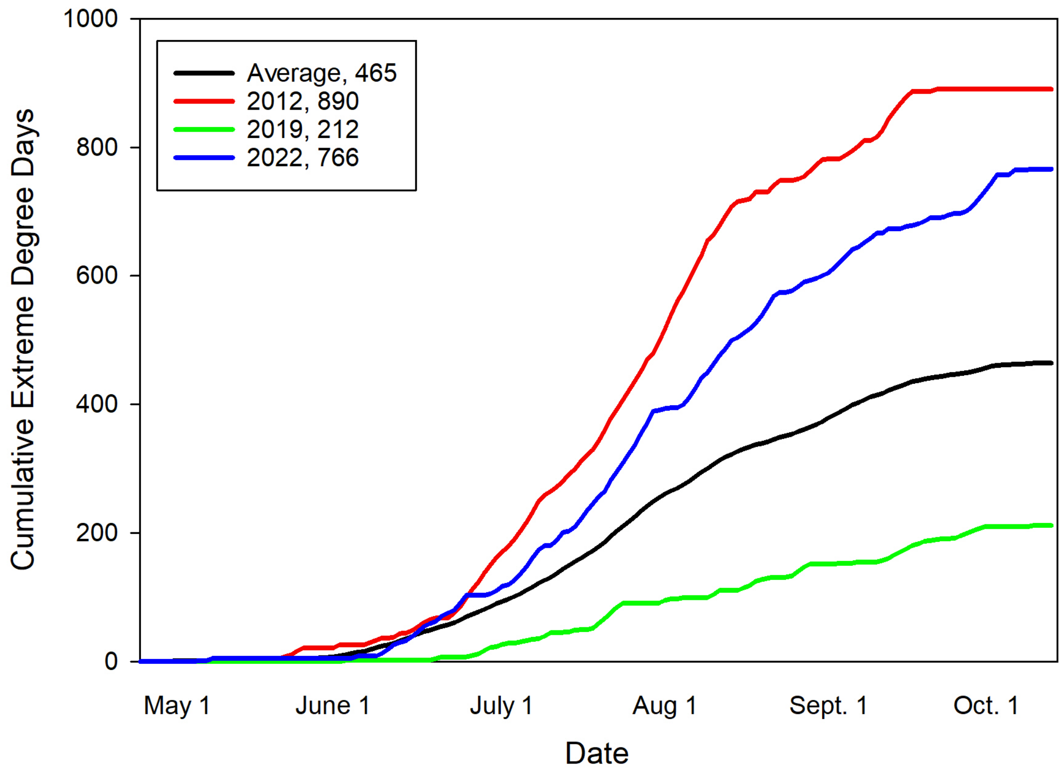

Figure 1. Cumulative extreme degree days (EDD, base 86) during the summer of 2019 (green), 2012 (red), 2022 (blue), and average of 12 prior years (black).

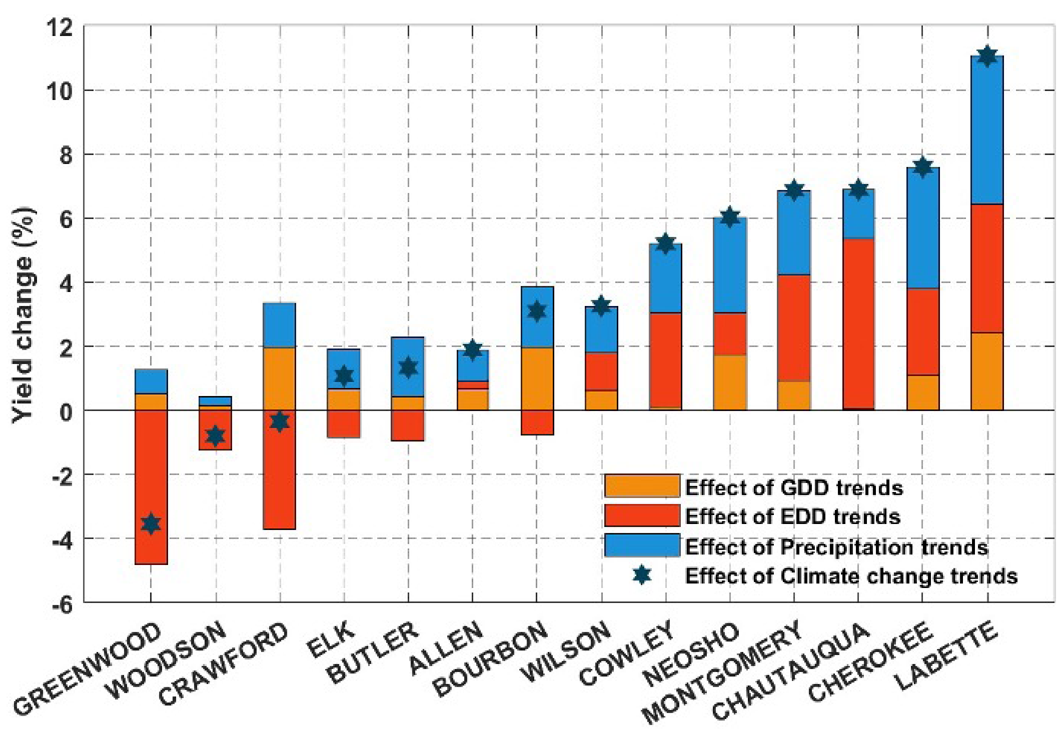

Figure 2. The impact of growing degree days (GDD), extreme degree days (EDD), and precipitation changes on corn yield from 1981 to 2019 per county.

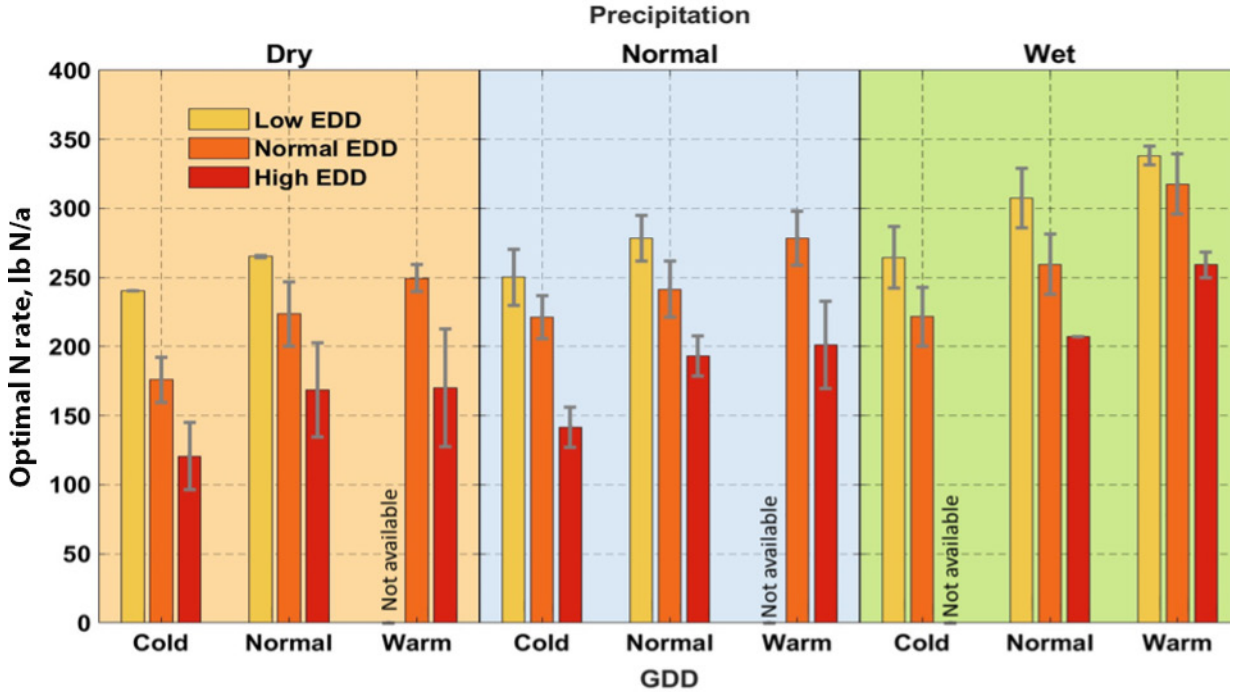

Figure 3. The optimal N fertilizer rate under different combinations of growing degree days (GDD), extreme degree days (EDD), and precipitation.

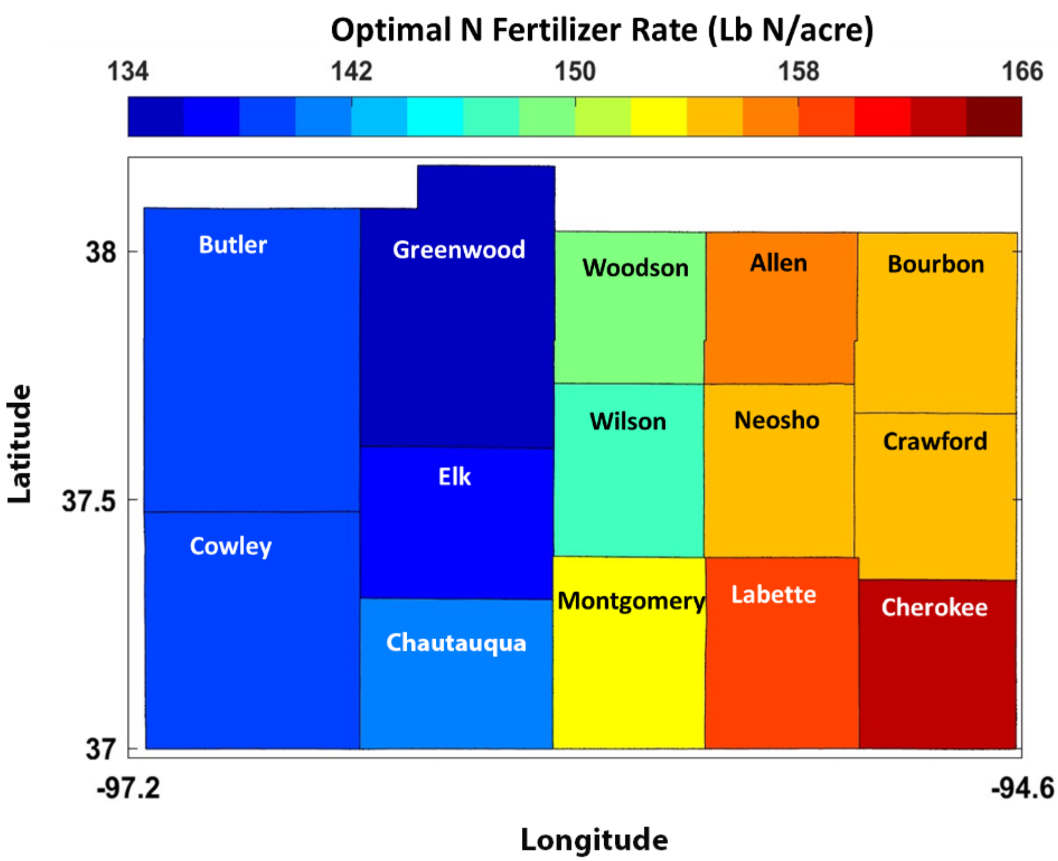

Figure 4. The optimal N fertilizer rate under average growing degree days (GDD), extreme degree days (EDD), and precipitation from 1981 to 2020 for the 14 counties in southeastern Kansas.