

Simulation modeling of cotton yield responses to management strategies under climate change: insights from DSSAT

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ABSTRACT

Forecasting cotton response to management strategies under climate change is considered an advanced tool for future planning to ensure global fiber security. An existing data set from a long-term cotton field experiment (39 years) at The University of Tennessee Institute of Agriculture Research and Education Center in Jackson was used for this project. This experiment consists of the complete combinations of two tillage systems (no-tillage and conventional tillage), and four nitrogen (N) application rates of 0, 30, 60, and 90 lb acre⁻¹. In this study, climate change impacts on cotton yield responses to management strategies were assessed using the DSSAT model for three projected periods (2030, 2040, and 2050) under the Representative Concentration Pathway 8.5 (RCP8.5). Results were compared with the baseline scenario of 1986–2018. As temperatures rise and rainfall decreases continuously from 2030 to 2050, the trend of cotton yield decreases becomes more pronounced in 2050 compared to 2040 and 2030. Under future climate change, lint yield will suffer severe damage from no or low N application, and intensive conventional tillage. There will be under greater need that apply a high N rate to cotton under no-till production than conventional tillage. Overall, a combination of 60 to 90 lb acre⁻¹ and no-tillage will be warranted to mitigate the negative effects of changing climate on lint yield. In conclusion, results from the DSSAT model provide management strategies on cotton for the future under changing climates. The best management system for future cotton production will be 90 lb acre⁻¹ under no-tillage.

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Introduction

The average temperature in the southeastern United States has increased by almost 1 C. Scientists predict that temperatures and extreme weather events, such as droughts and severe storms, will rise in Tennessee more than the global average (U.S. Environmental Protection Agency 2016). If global greenhouse emissions continue at the current rate, the temperature could increase by 2.8–3.5 C, and annual precipitation decrease by around 7–24% in Tennessee (Gao et al. 2012; Intergovernmental Panel on Climate Change 2007). Global agricultural production is already facing increased pressure from climate change (Wheeler and von Braun 2013). Additionally, due to the increasing population and limited land and water resources, the major challenge is how to sustain agricultural productivity to ensure global food and fiber security without risking other ecosystem services.

Cotton (*Gossypium hirsutum* L.) is a major crop in Tennessee, the USA, and the world. Forecasting cotton yields under climate change is considered an advanced tool for future planning to ensure global fiber security. However, it is largely unknown about the influences of climate changes on crop production such as cotton, particularly, which management strategies can and should be used in the future to mitigate the adverse impacts of climate changes in Tennessee, the Mid-southern states, and beyond. Therefore, this study will focus on many existing uncertainties related to the temperature and precipitation changes in cotton production. In this study, the state-of-the-art Decision Support System for Agrotechnology Transfer (DSSAT) model (Jones et al. 2003) is adopted to assess climate change impacts on cotton yield responses to management strategies. The DSSAT model has been demonstrated as a viable tool in several experiments for evaluating how both climatic factors and agricultural practices influence the growth and yield of cotton in the USA (Anapalli et al. 2016).

Through the utilization of a crop simulation model, it is possible to predict crop growth and yield by utilizing a set of genetic coefficients, initial soil parameters, crop management techniques, and weather variables (Teshome et al. 2024). Crop growth models play a critical role in selecting effective agronomic management strategies by enabling the examination of the interactions between environmental, physiological, and hereditary factors that affect plant growth. These models take into account complex attributes of plant growth (Mubeen et al. 2013). The CSM-CROPGRO-Cotton model, part of the DSSAT model, is such a crop model that simulates cotton growth, development, and yield under various weather and soil conditions and management practices (Jones et al. 2003; Ortiz et al. 2009).

Anapalli et al. (2016) found that there was an increase in seed cotton yield under moderate temperature rise (1.2–2.3 °C) due to climate change in the Mississippi Delta region, but yields decreased beyond 2050 under extreme temperature rise (2.6–4.6 °C); also, the impact of precipitation on seed cotton yield in 2050 was minimal as rainfall changes were insignificant and did not have any adverse effect. On the other hand, Rahman et al. (2018) reported a decrease in seed cotton yield of 12% in the 2030s (1.8 °C temperature rise) and 30% in the 2060s (3.5 °C temperature rise) in a study conducted in Punjab, Pakistan. Both studies, which utilized the CSM-CROPGRO-Cotton model, demonstrated that this model is useful for assessing the impacts of climate change on cotton production. However, the direction of future cotton yield change varied among the modeling studies.

The study aimed to (1) assess the impacts of climate changes on cotton production under the RCP8.5, a worst-case scenario, 2) cotton yield predictions under key management practices and projected future climate scenarios (2030, 2040, and 2050), 3) effects of long-term N fertilization on cotton lint yield (CLY), nitrogen use efficiency (NUE) and nitrogen agronomic efficiency (NAE).

Methods

Study region

The study was conducted at the University of Tennessee Institute of Agriculture's West Tennessee Research and Education Center (WTREC) in Jackson, TN, USA with a geographical location of 35°37'N: 88°51'W, altitude 113 m above mean sea level. The study area is generally flat to gently rolling topography with slopes of less than 2%. The soil of the study area is classified as the Lexington silt loam (fine-silty, mixed, thermic Ultic Hapludalfs) with its physical and chemical properties shown in Table 1.

The climate of this location is classified as humid subtropical (The Köppen climate classification for this region is Cfa) with an average annual temperature of approximately 15.5 °C. The area receives an average rainfall of 1,375 mm annually. Weather data is measured using an

Table 1. Soil physical and chemical properties at 0–15 and 15–30 cm depths in Jackson, TN.

Depth (cm)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	Sand (g kg ⁻¹)	Organic C (mg g ⁻¹)	pH	CEC (cmol kg ⁻¹)	Total N (mg g ⁻¹)	Bulk density (g cm ⁻³)
0–15	660	165	175	6.1	6.4	20	1.01	1.51
15–30	662	210	128	4.5	6.4	20	1.01	1.52

Figure 1. Annual precipitation and maximum, mean, and minimum temperatures during 1986–2018 at Jackson, Tennessee.

automated weather station located at the WTREC of the Institute. The daily and hourly monitored weather variables include temperature, rainfall, wind speed, relative humidity, and sunshine hours. [Figures 1](#) and [2](#) show the mean values of precipitation and temperature (maximum, minimum) for the baseline period (1986–2018) and three future years (2030, 2040, and 2050).

Field experiment

The experiment was originally initiated in 1986 at the University of Tennessee Institute of Agriculture's West Tennessee Research and Education Center in Jackson, Tennessee. The field experiment on the cotton crop was conducted under the complete combinations of two tillage systems: conventional (CT, chisel plow) and no-tillage (NT); and four N application rates: 0 (N0), 30 (N1), 60 (N2), and 90 (N3) lb acre⁻¹. The field experiment was a randomized complete block with a split-plot design with N rates as the main plots, and tillage systems as the subplots, with four replicates. The crop was sown at a depth of 4 cm with each resulting sub-subplot having a dimension of 12 m by 8 m which included eight rows of cotton. Cotton was uniformly seeded on the entire plot targeting about 86,500 plants ha⁻¹. The tilled treatments were double-disked to a depth of 10 cm and were harrow-leveled to prepare the seedbed. During the experiment, different cotton cultivars were planted, which included Stoneville 825, Deltapine 50, Stoneville, Deltapine 50, Stoneville 474, Deltapine 425, Deltapine 451, and Phytogen 375. Irrigation was done based on the effective root zone depth's soil water content. Cotton was harvested mechanically and ginned, and lint yield was recorded in October each year.

Different crop parameters were measured at major crop growth stages: initial, vegetative, maturing, and harvesting. The whole plant samples were further separated into different parts similar to the sampling during the growing season (emergence, anthesis, and physiological maturity) and then oven-dried to constant weight at 70 °C.

The utilization of applied N by cotton was evaluated in terms of N agronomic efficiency (NAE) and use efficiency (NUE). Nitrogen use efficiency and nitrogen agronomic efficiency were calculated using the following [Equations \(1\) and \(2\)](#) (Li et al. 2017).

$$\text{NUE} = \frac{Y_t - Y_0}{N_t - N_0} \times 100$$

(1)

Figure 2. Monthly precipitation (a) and maximum (b), minimum (c), and mean (d) temperatures during 2030, 2040, and 2050 in Jackson, Tennessee.

$$NAE = \frac{1}{N} \sum_{i=1}^N |Y_t - Y_0| \quad (2)$$

where Y_t is the total yield in the fertilized plot, Y_0 is the total yield in the control plot and N is the total amount of N applied.

Climate scenarios

The inputs of climate data derived from the Weather Research and Forecasting (WRF) model were used to drive the DSSATv4.7 model. Climate data, including daily precipitation, maximum and minimum temperatures, and solar radiation, were generated with WRF for both the present climate (1986–2018) and the future climate (2030, 2040, and 2050) under RCP8.5, defined as a worst-case scenario with limited climate mitigations (Intergovernmental Panel on Climate Change 2007).

Crop modeling

Crop growth modeling

Crop management data for the cotton growing season of 2009 was used for model calibration and data for 2010 was used for model validation. Standard meteorological, soil, plant characteristics, and crop management data were obtained for the experimental region and used as input data for the model. The DSSAT model was used for the estimation of crop genetic coefficients using sensitivity analysis to select the best treatment.

Model calibration and validation

Twelve cultivar parameters and five ecotype parameters were adjusted until the simulated crop development stages and cotton yields matched reasonably well with measured data collected in

Table 2. Parameters adjusted during the CSM-CROPGRO-cotton model calibration.

Parameters	Description	Testing range	Calibrated value
<i>Cultivar parameters</i>			
EM-FL	Time between plant emergence and flower appearance (photothermal days)	34–44	39
FL-SH	Time between first flower and first pod (photothermal days)	6–12	8
FL-SD	Time between first flower and first seed (photothermal days)	12–18	15
SD-PM	Time between first seed and physiological maturity (photothermal days)	42–50	40
FL-LF	Time between first flower and end of leaf expansion (photothermal days)	55–75	57
LFMAX	Maximum leaf photosynthesis rate at 30 C, 350 ppm CO ₂ , and high light (mg CO ₂ m ⁻² s ⁻¹)	0.7–1.4	1.05
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm ² g ⁻¹)	170–175	170
SIZLF	Maximum size of full leaf (three leaflets) (cm ²)	250–320	300
XFRT	Maximum fraction of daily growth that is partitioned to seed $i_{\frac{1}{2}}^{\text{shell}}$	0.7–0.9	0.7
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	22–35	34
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)	8–14	14
THRSH	Threshing percentage. The maximum ratio of [seed/ (seed $i_{\frac{1}{2}}^{\text{shell}}$)] at maturity.	68–72	70
<i>Ecotype parameters</i>			
PL-EM	Time between planting and emergence (thermal days)	3–5	4
EM-V1	Time required from emergence to first true leaf, thermal days	3–5	4
RWDTH	Relative width of the ecotype in comparison to the standard width per node	0.8–1.0	1
RHGHT	Relative height of the ecotype in comparison to the standard height per node	0.8–0.95	0.9
FL-VS	Time from first flower to last leaf on main stem (photothermal days)	40–75	57

2009 (Table 2). The data on phenology, development, and growth for the year 2010 were used for validation of the CROPGRO Cotton model. The simulated dates of various cotton development stages were compared with generally observed dates in the study area (Table 3). The simulated dates of onset of various cotton development stages such as emergence, anthesis, and physiological maturity during calibration and validation over cotton growing seasons at Jackson, Tennessee are within the ranges suggested by Adhikari et al. (2016) (Table 3).

The crop model performance was examined by comparison of observed and simulated values for the crop parameters. Hence, three deviation statistics, including determination (R^2), index of agreement (d), and root mean square error (RMSE), were employed to evaluate the CROPGRO-Cotton model, calculated using Equations (3) (4), and (5), respectively. The R^2 values range between 0 and 1, with 0 indicating ‘no fit’ and 1 indicating ‘perfect fit’ between the simulated and observed values. The RMSE values closer to 0 indicate better agreement between the simulated and observed values. The model calibration effort was carried out until RMSE was low, and R^2 was higher than 0.80. The parameters were adjusted until the simulated crop development stages and yields matched reasonably well with the measured data (Table 3).

$$R^2 = \frac{\sum_{i=1}^N (Y_i - \bar{Y})^2 - \sum_{i=1}^N (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^N (Y_i - \bar{Y})^2}$$

(3)

Table 3. Comparisons of simulated and generally observed dates of onset of cotton phenological stages.

Crop phenological stage	Observed (days after planting)	Simulated (days after planting)
	Calibration	
Emergence	4–9	8
Anthesis	60–70	64
Physiological maturity	130–160	156
	Validation	
Emergence	4–9	7
Anthesis	60–70	63
Physiological maturity	130–160	145

Robertson et al. (2007).

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (Y_i - \hat{Y}_i)^2}{N}} \quad (4)$$

$$d = 1 - \frac{\sum_{i=1}^N (Y_i - \bar{Y}_i)^2}{\sum_{i=1}^N (Y_i - \bar{Y}_i)^2 + \sum_{j=1}^N (\hat{Y}_j - \bar{\hat{Y}})^2} \quad (5)$$

where Y_i , observed value, \hat{Y} simulated value, \bar{Y}_i , average of simulated value, \bar{Y} , average of observed value, N , number of observations.

Results

Cotton lint yield evaluation under no-tillage and conventional tillage during 1986–2018

The measured CLY changed dramatically between the years. From 1986 to 2018, CLY varied from 273 to 1182 lb/acre for the N0 treatment, from 288 to 1381 lb/acre for the N1 treatment, from 302 to 1526 lb/acre for the N2 treatment, and from 428 to 1331 lb/acre for the N3 treatment under conventional tillage (Figure 3(a)). While under no-tillage CLY was from 368 to 1204 lb/acre for the N0 treatment, from 413 to 1306 lb/acre for the N1 treatment, from 420 to 1401 lb/acre for the N2 treatment and from 384 to 1458 lb/acre for the N3 treatment under conventional tillage (Figure 4(a)).

Nitrogen use efficiency is defined as the ratio between the harvested product (grains, fibers, or dry matter) and the N dose applied. Nitrogen is a vital nutrient for agriculture, and a deficiency of it causes stagnate cotton growth and yield penalty. Farmers rely heavily on N over-application to boost cotton output, which can result in decreased lint yield, quality, and NUE. Therefore, improving NUE in cotton is crucial for reducing environmental nitrate pollution and increasing farm profitability. Nitrogen fertilizer plays a vital role in increasing cotton yield, but its excessive application leads to lower yield, lower NUE, and environmental pollution (Noor Shah et al. 2022). The increase of the N rate decreased NAE and NUE under both tillage systems (Figures 3 and 4(b)).

There was a reduction in NAE with the increase of N fertilization in this study under both no-tillage and conventional tillage (Figures 3 and 4(c)). This result is in good agreement with several other studies (Rochester 2011; Dong et al. 2012; Stamatiadis et al. 2016).

Cotton cumulative probability distribution under different nitrogen fertilizers

Based on cumulative probability distribution (Figure 5(a)) under no-tillage system, the CLY was higher in the N2 and N3 treatments than in the N0 and N1 treatments. There was a 50% probability that CLY exceeded 823.61 lb/acre in the N0 treatment, 1365.21 lb/acre in the N2, and

Figure 3. Measured CLY, NUE, and NAE at different nitrogen levels under conventional-tillage system at Jackson, Tennessee.

Figure 4. Measured CLY, NUE, and NAE at different nitrogen levels under no-tillage system at Jackson, Tennessee.

1394.22 lb/acre in the N3 treatments, suggesting that N application did cause yield increases in the current study.

In the long-term experiment, the cumulative density distribution of crop yields was calculated under different N management strategies. Generally, if the cumulative density distribution of one strategy was higher than that of another strategy over the entire probability range (0–1.0), the strategy was considered to have a stochastic dominance (Singh et al. 1999). Under conventional tillage system, the CLY was higher in the N3 treatment than that in the N0 and N1 and N2 treatments (Figure 5(b)). There was a 50% probability that CLY surpassed 806.34 lb/acre in the N0 treatment, 986.27 lb/acre in the N1, 1142.87 lb/acre in the N2 and 1298.55 lb/acre in the N3 treatments. The current study suggests that the application of N resulted in increased yields.

Calibration and validation for CLY

The DSSAT model performed well under the climatic conditions of Jackson, Tennessee. Scattered plots were made to evaluate the relative closeness between the simulated and observed data for CLY in 2009 and 2010 (Figure 6) under no-tillage and conventional tillage systems. The results indicate a close matching between simulated and observed data for all the N rate treatments under both tillage systems. The *d*-stat value remained between 0.8 and 0.9 in all the cases indicating excellent simulation by the model in both tillage systems. The R^2 value was obtained with the linear regression analysis of functions between measured and simulated values of CLY. Evaluation results of crop yield were good having an R^2 value greater than 0.8 for most of the parameters and values close to the 1:1 line indicating that the model accurately simulated the yield. The calibrated values of CLY were 1159, 1249, 1255, and 1301 lb/acre (observed) and 1163, 1201, 1198, 1371 lb/acre (simulated) at N0, N1, N2, and N3 under no-tillage, respectively (Figure 6(a)) and for conventional tillage, CLY were 1159, 1249, 1255, and 1301 lb/acre (observed) and 1163, 1201, 1198, 1371 lb/acre (simulated) at N0, N1, N2, and N3, respectively (Figure 6(b)).

Validation results showed that the cotton crop gave higher values of CLY under all N rate treatments under conventional tillage as compared to no-tillage, and the observed values were somewhat closer to simulation results. The validated values of CLY were 1176, 1269, 1288, 1342 lb/acre (observed) and 1147, 1151, 1189, and 1162 lb/acre (simulated) at N0, N1, N2, and N3 under no-tillage, respectively (Figure 6(c)). Overall validated value at N0, N1, N2, and N3 under conventional tillage was 1208, 1297, 1301, 1312 lb/acre (observed) and 1143, 1134, 1201, 1138 lb/acre (simulated) (Figure 6(d)). Higher rate of N resulted in higher value of CLY according to simulation results (Chen et al. 2019; Sui, Byler, and Delhom 2017).

Figure 5. Cumulative probability distribution for cotton yield at different nitrogen levels under no-tillage (a) and conventional tillage (b) from 1986 to 2018 at Jackson, Tennessee.

Figure 6. Relationship between simulated and observed values of CLY at different N rates for no-tillage (a) and conventional tillage (b) in 2009 (a, b) and 2010 (c, d) at Jackson, Tennessee.

Responses of CLY to N rates, and tillage systems in the future years

The CROPGRO-Cotton model was run to predict CLY for the baseline period (1986–2018) for four N rates under two tillage systems (Figure 7). In the baseline years, CLY generally went up with the increment in N rate from N0 to N1, N2, and N3, and it was significantly higher at N3 than the other lower N rates under no-tillage (Figure 7). The CROPGRO-Cotton model was also run to predict CLY for the upcoming years of 2030, 2040, and 2050 under the RCP8.5 scenario, respectively, for four N rates under two tillage treatments (Figure 7(a,b)). Under the no-tillage system, CLY exhibited a declining trend at N0 and N1 during the years 2030, 2040 and 2050 diverging from the baseline. Conversely, at N3, CLY in 2040 demonstrated an increase compared to the baseline, while no significant change was observed in 2030 and 2050 in comparison to the baseline. Notably, at N4, it consistently increased each year, reaching its highest point in 2040 (Figure 7(a)).

Under conventional tillage, at N0 and N1, CLY decreased in 2030 and 2050 while no significant change in 2040 compared to the baseline. At N3, CLY showed a declining trend in 2030 and 2040 but decreased in 2050 (Figure 7(b)). CLY indicated an increasing trend during 2030, 2040 and 2050. These results suggest that N3 is mostly required for conventional-till cotton to produce the highest yield.

Overall, our study showed that N3 was warranted for cotton to produce the highest yield under both tillage systems in the upcoming years.

Comparisons of CLY responses to N rates, and tillage systems between upcoming years under climate change and baseline years

In comparison with the baseline results, the change in yield at the four N rates (N0, N1, N2, and N3) recorded was –18.0%, –12.6%, 1.3%, and 15.0% respectively for 2030, while –14.8%,

Figure 7. Average CLY at different N rates for no-tillage (a) and conventional tillage (b) at Jackson, Tennessee during 2030, 2040, and 2050 relative to the baseline period (1986–2018).

1.1%, 3.4%, and 12.1% respectively for 2040, and –25.5%, –2.6%, –3.8%, and 10.1% respectively for 2050 under no-tillage (Figure 8(a)). In conventional tillage, the yield change at N0, N1, N2, N3 recorded was –11.4%, –19.5%, 5.3%, and 11.1% respectively with the time of 2030, while –2.8%, 1.7%, 6.3%, and 9.2% for 2040 and –27.7%, –23.9%, 2.7%, and 8.2% for 2050 (Figure 8(b)).

As observed, CLY in the N0 treatment declined under both no-tillage and conventional tillage over the upcoming years, with a more pronounced decrease in 2050 compared to 2030. Cotton lint yield at the N2 level in both tillage systems exhibited a declining trend, except for the year 2040, which indicated a small increase of 1.1% and 1.7% respectively, in comparison to the baseline yield. However, in both tillage treatments, CLY at N2 and N3 demonstrated a consistent upward trend in almost all the future years, surpassing the baseline results. For instance, CLY at N3 under no-tillage was 15.0%, 12.1%, and 10.1% higher than the baseline result, while in conservation tillage it showed a respective increase of 11.1%, 9.2%, and 12.3% compared to the baseline value.

Overall, these results showed the effects of the N application rate on CLY were similar between conventional tillage and no-tillage except that the highest N rate N3 resulted in a greater positive effect on CLY under no-tillage for the upcoming years under climate change relative to the baseline period. Therefore, there is under greater need that applies a high N rate such as N3 to cotton under no-till production in the future under climate change.

Figure 8. Change in CLY due to climate change with respect to the baseline period (1986–2018) in Jackson, Tennessee at RCP 8.5 at different N rates under no-tillage (a) and conventional tillage (b).

Discussion

The increase of the N rate decreased NAE and NUE under both tillage systems. A high nitrogen use efficiency means that more of the applied nitrogen is taken up by the crop and has a positive impact on both the environment and farmers' profits. Furthermore, it is a measure of the amount of N taken up by a crop compared to the amount applied. It is an important indicator of environmental sustainability and economic efficiency in crop production because it shows the relationship between N inputs and crop yield (Dong et al. 2012). Stamatiadis et al. (2016) reported that there was a negative relationship between N rate and NAE and NUE.

The CROPGRO-Cotton model under DSSAT has been tested by researchers for growth and yield simulation of cotton sown under different climatic conditions with different crop management practices (Jones et al. 2003; Ortiz et al. 2009). CROPGRO-Cotton is capable of estimating climatic impacts on cotton crops (Amouzou et al. 2018). Quantification of climatic impact on Tennessee cotton with the model is vitally important. First-year data for calibration and second-year data for validation have been used in many researches (Mubeen et al. 2013; Wajid et al. 2013). It provides a basis to evaluate model accuracy under various agro-climatic conditions. Li et al. (2009) confirmed that CROPGRO-Cotton simulates days to flowering and maturity close to the observed values with RMSE lower than 3 days. The DSSAT model overestimated CLY indicating that there is a potential for cultivars to produce more CLY under these sets of agro-ecological conditions. Model validation in the second year was also good. Experimental results of this study are in line with those of Ortiz et al. (2009). The model predicted CLY with acceptable RMSE and good agreement of d statistic between observed and simulated data in this study.

In the future years (2030, 2040, and 2050), cotton yield was found to be lower under conventional tillage compared to no-tillage. With the projected increase in temperature in the future, adopting a no-tillage approach for cotton cultivation can offer certain advantages. First, no-tillage

systems help conserve soil moisture by reducing evaporation. Second, no-tillage promotes better soil structure and stability. The undisturbed soil allows for the development of deeper and more extensive root systems, which can enhance the plant's access to water and nutrients, even under higher temperatures. This can contribute to improved overall plant health and productivity. Additionally, the crop residues left on the soil surface in a no-tillage system act as a barrier reducing direct exposure of the soil to sunlight. This helps moderate soil temperature and reduces the risk of overheating, which can be detrimental to cotton plants (Cid et al. 2014; Singh et al. 2023; Teodor 2014).

As the model estimate shows, the amount of precipitation will decrease and the temperature will increase in Tennessee, which leads to a decrease in CLY in this study. DSSAT model results are in line with those of Lobell and Asseng (2017) and Singh et al. (2007) who confirmed that heat stress and other climatic shocks will reduce crop yield. Moreover, the present study also confirms that increasing RCP increases the chance of yield loss because of a higher radiative force of 8.5 W/m^2 (Riahi et al. 2011) enforced by higher emission of greenhouse gas, which increases the higher intensity of solar radiation and extreme temperature events causing severer soil water stress and accelerating crop phenology that leads to a shorter growing period (Zhao et al. 2017). The increased temperature affects the frequent heat waves and possible temperature impact on weeds, pests, and diseases which reduce the yield (Subedi, Poudel, and Aryal 2023). Ainsworth and Ort (2010) found that higher temperatures during reproductive stages affect fertilization and grain formation which can severely affect crop yield.

Based on previous crop simulations, some key processes and their interactions account for the detrimental effect of temperature increase on crop yield for long-term projections (Jones et al. 2003). A higher increase in temperature leads to heat stress which results in a reduction in biomass production (Challinor et al. 2014; Hatfield and Prueger 2015). Also, according to several studies, the number of maturity days (from sowing to harvest) is predicted to shrink, ranging from about 10 to 30 days shorter in the next few decades, which will also result in reduced biomass production (Tao et al. 2015; Zhao et al. 2017).

The CLY, based on the aboveground biomass, increased under the climate in 2030 while decreasing for 2050 compared to the baseline value. These results indicate that the level of N3 might have beneficial effects on cotton in the medium-term due to the slight increase in temperature relative to the baseline period. The expected reduction of precipitation during the growing season of cotton for 2050 which is higher than for 2030 has a major negative impact on crop production. During 2050 when the warming was higher than during 2030 and 2040 under RBC8.5, CLY was found to decrease more.

Generally, the temperature increased and rainfall decreased in 2040 compared to 2030. This change in climate conditions could have contributed to higher cotton yields in 2040 despite the challenges. The elevated temperatures in 2040 might have accelerated microbial activity in the soil, resulting in increased nutrient (N, P, and S) mineralization and availability (Jansson and Hofmockel 2020). As a result, cotton plants could have experienced enhanced nutrient uptake, supporting their growth and yield potential, even with reduced rainfall. This could be one of the reasons why CLY was higher in 2040 than in 2030 at low N rates (N0 and N1).

The findings suggest that a combination of N3 fertilizer under a no-tillage system can be highly effective in maximizing cotton yield in the future under changing climates. No-tillage helps improve soil health, increase water retention, and reduce soil erosion. No-till systems conserve soil moisture and create a more resilient environment for cotton growth (Mitchell, Shrestha, and Munk 2016). These management practices are expected to enhance soil health, increase nutrient availability, and improve water retention, ultimately resulting in higher cotton productivity and improved resilience to changing climate conditions. This research sets the stage for more studies, helps farmers improve, and can make farming better, especially with changing weather.

Conclusion

The effects of climate change on CLY in the area of Jackson, Tennessee were assessed in this study. For all four N application rates, the variation of the simulated CLY values with the CROPGRO-Cotton model suggests that the model is successful in predicting the lint yield variation. The coefficient of determination was calculated at 0.9, and the index of agreement (d) was mostly greater than 0.8 for both tillage systems, indicating a high performance of the model.

Simulation results suggest that temperature and precipitation can exert a significant effect on cotton production. The WRF model indicated an increase in future maximum and minimum air temperatures but a decrease in precipitation for all upcoming years (2030, 2040, and 2050) of climate change relative to the baseline period (1986–2018).

The yields predicted with the CROPGRO-Cotton model showed that in the future under climate change, lint yield will suffer severe damages from no or low N application, and/or intensive conventional tillage, but will receive greater benefits from high N application, and/or no-tillage relative to the baseline period. There will be under greater need that applies a high N rate to future cotton under no-tillage than conventional tillage. Overall, a combination of 60 to 90 lb acre⁻¹ under no-tillage will be warranted to mitigate the negative effects of changing climates under RCP8.5 on future cotton production.

It is concluded that the DSSAT model can be an effective tool for making strategic cotton management choices in the future under changing climates. The best management systems will be N3 integrated under no-tillage for future cotton production. The climate change will have serious impacts on the agricultural sector and adaptation and mitigation measures can and should play an important role in reducing these adverse impacts.

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