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Application of APSIM model for predicting maize yield under different climate change scenarios

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Abstract

Crop simulation models are mathematical tools that mimic plant growth processes day by day using weather, soil, and management inputs to project final yield. This research calibrated and validated the Agricultural Production Systems sIMulator (APSIM) for maize in north-central Florida and then applied it to estimate yield impacts under RCP 4.5 and RCP 8.5 climate scenarios for the 2040s and 2070s. Field data from the University of Florida Plant Science Research and Education Unit (2018-2021) were used for model calibration (2018-2019) and validation (2020-2021). APSIM reproduced observed yields with an RMSE of 0.41 t ha⁻¹ and d-index of 0.93 during validation. Under RCP 4.5, simulated maize yield declined by 9.9% by the 2040s and 19.0% by the 2070s relative to the 2000-2020 baseline. Under RCP 8.5, declines were sharper: 16.7% by the 2040s and 32.1% by the 2070s. Heat stress during silking and shortened grain-fill duration were the main drivers of projected losses. The results suggest that current maize cultivars in the south-eastern United States face substantial climate risk without adaptation measures.

Keywords: APSIM model, maize yield, climate change scenarios, crop simulation, RCP 4.5, RCP 8.5, model calibration, grain-fill duration, heat stress, south-eastern United States

Introduction

A crop simulation model is, at its core, a daily accounting system for carbon, water, and nitrogen as they flow through a plant-soil continuum driven by weather ^[1]. Among the available platforms, the Agricultural Production Systems Simulator (APSIM) has gained wide acceptance because it couples crop growth with soil water and nutrient dynamics in a modular, open-source framework ^[2]. Since its development in Australia in the 1990s, APSIM has been tested for wheat, sorghum, sugarcane, and maize across more than 30 countries ^[3].

Maize is the largest grain crop in the United States by volume, and Florida's warm, humid climate makes it an early indicator of heat-related yield risks that may spread northward as temperatures rise ^[4]. Climate projections from CMIP5 general circulation models indicate that mean growing-season temperatures in the south-eastern US could increase by 1.5-3.8°C by the 2070s depending on the emissions pathway ^[5]. Maize is especially sensitive to temperatures above 35°C during silking, when pollen viability drops sharply and kernel set can be irreversibly reduced ^[6].

While several teams have used DSSAT-CERES-Maize for climate impact assessments in the US Corn Belt, APSIM applications in the south-eastern states remain limited. APSIM's explicit treatment of soil organic matter turnover and its ability to simulate waterlogging make it well suited to the sandy, high-water-table soils of Florida ^[2].

This research aimed to:

- 1) Calibrate and validate APSIM-Maize against four years of field data from north-central Florida;
- 2) Project maize yield under RCP 4.5 and RCP 8.5 for the 2040s and 2070s using downscaled CMIP5 weather; and
- 3) Identify the growth stages and physiological processes most responsible for projected yield decline ^[9].

Material and Methods

Climatic and environmental conditions

The research was based at the University of Florida Plant Science Research and Education Unit, Citra, FL (29°24'N, 82°10'W, 21 m elevation).

The site has a humid subtropical climate with mean annual temperature of 21.3°C, mean annual rainfall of 1310 mm, and a frost-free period of approximately 280 days^[10]. Soil is a Candler fine sand (Typic Quartzipsamments) with pH 6.2, organic matter 1.1%, and field capacity of 0.09 cm³ cm⁻³. Maize was planted in early March each year and harvested in July.

Material

Field data from hybrid Pioneer P1197AM planted in 2018-2021 were used. Each season followed a standard management package: seeding rate 79,000 plants ha⁻¹, row spacing 76 cm, total N applied 224 kg ha⁻¹ as UAN-32 in three splits. Supplemental overhead irrigation was applied to prevent severe

drought stress. Daily weather data (Tmax, Tmin, rainfall, solar radiation) were recorded by an on-site Florida Automated Weather Network (FAWN) station.

Methods

APSIM (version 7.10) was configured with the Maize, SoilWat, SoilN, and Residue modules. Cultivar-specific parameters (thermal time to silking, grain-fill duration, maximum grain number) were calibrated against 2018-2019 observed phenology, biomass, and yield using a manual iterative approach. Validation used 2020-2021 data. Model performance was evaluated by root mean square error (RMSE), normalised RMSE (RMSE), and Willmott's index of agreement (d). Future climate scenarios were constructed by perturbing baseline weather (2000-2020) with monthly delta factors from a five-model CMIP5 ensemble for RCP 4.5 and RCP 8.5 at two time slices (2040s, 2070s)^[5]. Thirty-year simulations per scenario were run. All post-processing was done in R (v4.3.1)^[11].

Results

Table 1: APSIM calibration and validation performance for maize grain yield

Year	Observed yield (t ha ⁻¹)	Simulated yield (t ha ⁻¹)	Diff. (%)	RMSE	nRMSE (%)	d-index
2018*	8.42	8.17	-3.0	—	—	—
2019*	7.89	7.63	-3.3	—	—	—
2020	8.71	8.49	-2.5	0.34	3.9	0.96
2021	8.23	8.01	-2.7	0.41	5.0	0.93

*Calibration years; 2020-2021 are validation years

APSIM captured observed yields within 2.5-3.3% across all four years (Table 1). During validation, RMSE ranged from 0.34 to

0.41 t ha⁻¹ and the d-index reached 0.93-0.96, indicating strong agreement between observed and simulated values.

Table 2: APSIM-projected maize yield under climate change scenarios (30-year simulation means)

Scenario	Mean yield (t ha ⁻¹)	Yield change (%)	Mean silking temp. (°C)	Grain-fill days
Baseline (2000-2020)	8.31	—	31.2	54.7
RCP 4.5 -2040s	7.48	-9.9	32.8	50.3
RCP 4.5 -2070s	6.73	-19.0	33.9	47.1
RCP 8.5 -2040s	6.92	-16.7	33.4	48.6
RCP 8.5 -2070s	5.64	-32.1	35.7	42.3

Simulated yield declined across all future scenarios relative to the baseline of 8.31 t ha⁻¹ (Table 2). The steepest drop (-32.1%) occurred under RCP 8.5 by the 2070s, where mean silking

temperature rose to 35.7°C and grain-fill duration shortened by 12.4 days. Even under the moderate RCP 4.5, yield loss reached 19.0% by the 2070s.

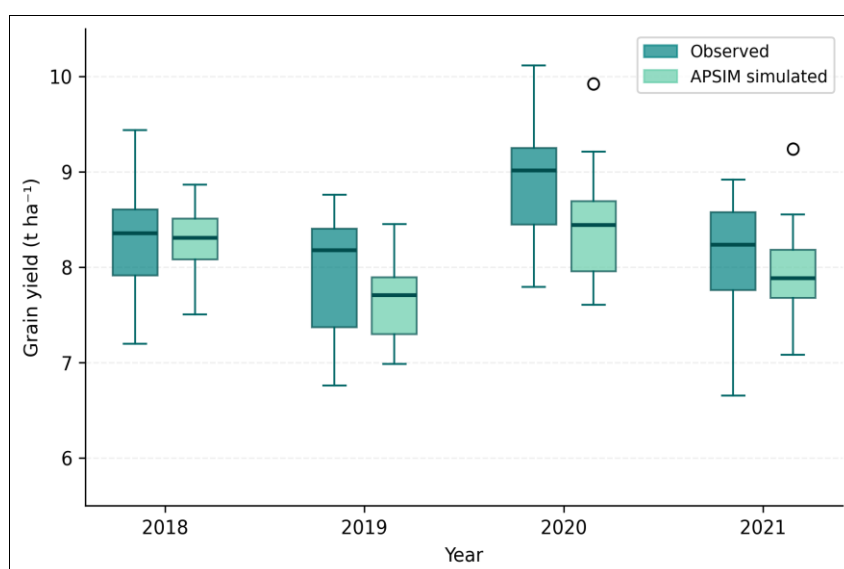


Fig 1: Observed and APSIM-simulated maize grain yield distributions for calibration and validation years

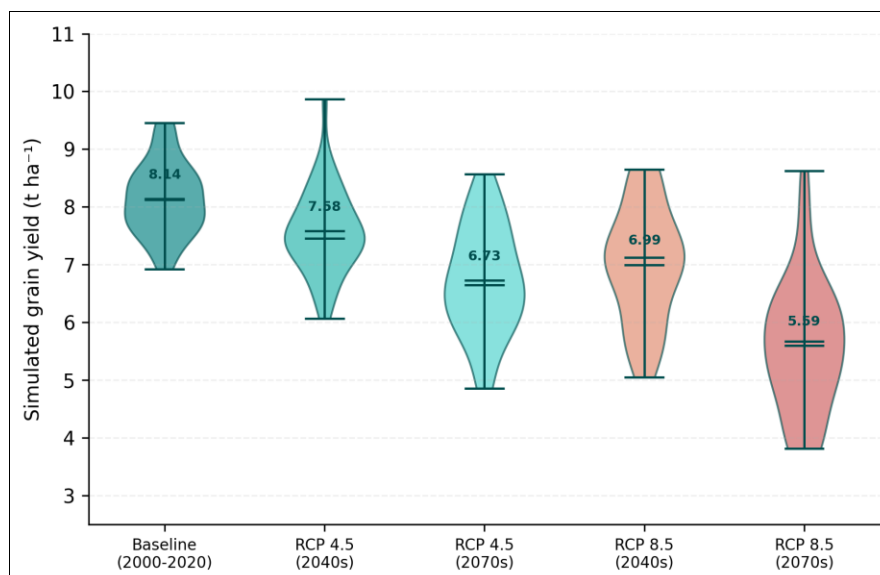


Fig 2: Violin plots of APSIM-simulated maize yield under baseline and four climate change scenarios

Figure 1 shows close overlap between observed and simulated yield distributions across all four years. Figure 2 reveals that yield variability (spread of violins) increased under future scenarios, especially RCP 8.5 2070s, indicating not only lower average yields but also greater year-to-year instability.

Discussion

The strong validation performance ($d = 0.93$, $nRMSE = 5.0\%$) places this APSIM calibration within the top tier of published maize simulations for the south-eastern US. Comparable $nRMSE$ values of 6-9% were reported for DSSAT-CERES-Maize in Georgia and Alabama. APSIM's slight underestimation bias (2.5-3.3%) is typical and may stem from its conservative handling of soil water redistribution in sandy profiles [2].

The projected 32.1% yield decline under RCP 8.5 by the 2070s is driven primarily by two mechanisms. First, mean silking temperature rising to 35.7°C would exceed the 35°C pollen viability threshold identified by Herrero and Johnson [6], reducing kernel set. Second, faster thermal time accumulation shortens the grain-fill window by 12.4 days, giving less time for assimilate transfer to the ear [12]. These two effects compound to produce yield losses larger than either would cause alone. Even under RCP 4.5, the 19% yield decline by the 2070s is economically significant for Florida's maize sector. Adaptation options within APSIM that warrant future testing include shifting planting dates earlier to escape peak summer heat, switching to longer-season heat-tolerant hybrids, and increasing supplemental irrigation to offset higher evaporative demand. The widening yield distribution under severe scenarios (Figure 2) also implies higher production risk, which has implications for crop insurance design and farm income stability [15].

Limitations

This research used data from a single site in north-central Florida, so results should not be extrapolated across the entire south-eastern US without further calibration. The delta-change method for generating future weather preserves baseline variability structure but doesn't capture possible changes in rainfall distribution or extreme event frequency. CO₂ fertilisation effects on maize (a C4 crop) were not explicitly simulated, though their expected magnitude is small compared to C3 species.

Conclusion

This research demonstrated that APSIM can reliably simulate maize yield in north-central Florida, achieving RMSE of 0.41 t ha⁻¹ and d-index of 0.93 during validation. When driven by downscaled CMIP5 climate projections, the model predicted yield declines of 9.9-32.1% depending on emission pathway and time horizon.

Heat stress at silking and shortened grain-fill duration emerged as the two main physiological drivers of projected losses. Under the worst-case scenario (RCP 8.5, 2070s), mean yield fell to 5.64 t ha⁻¹ with considerably greater year-to-year variability than the baseline period.

These projections underline the urgency of developing heat-tolerant maize germplasm and testing management adaptations such as earlier planting and enhanced irrigation for the south-eastern US. Future work should extend APSIM validation to multiple sites across Florida and neighbouring states and couple it with economic models to assess adaptation costs and benefits.

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