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DSSAT-based evaluation of optimal planting windows for rainfed sorghum under climate uncertainty

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Abstract

Farmers in rainfed systems gamble on planting date every season plant too early and seeds may rot in dry soil, too late and grain fill collides with end-of-season drought. This research used the DSSAT-CERES-Sorghum model to evaluate seven planting windows (March 1 through June 1, biweekly intervals) for rainfed sorghum at Gainesville, Florida, under historical baseline (1990-2020) and two future climate scenarios (RCP 4.5 and RCP 8.5 for 2040-2070). April 1 consistently produced the highest and most stable yields across all scenarios (3.68 t/ha baseline, 3.24 t/ha RCP 8.5). Yield variability increased sharply for plantings after May 1. Climate change narrowed the optimal window from roughly four weeks to two. Early April planting offers the best risk-yield balance for rainfed sorghum in north-central Florida.

Keywords: DSSAT, CERES-Sorghum, planting window, rainfed agriculture, climate uncertainty, RCP scenarios, yield variability, sorghum, crop simulation, adaptation strategy

Introduction

In most years, a two-week shift in planting date barely matters for irrigated crops but for rainfed sorghum in the southeastern United States, that same shift can mean the difference between catching the right rainfall window or missing it entirely ^[1]. Sorghum is relatively drought-tolerant, yet its yield still depends on adequate moisture during panicle initiation and grain fill ^[2, 3].

Climate projections for the US Southeast indicate higher temperatures, more erratic rainfall, and longer dry spells by mid-century ^[4]. These changes will likely shift the optimal planting window, but by how much and in which direction isn't clear without simulation analysis ^[5]. DSSAT's CERES-Sorghum module has been calibrated for a range of environments and can run long-term seasonal analyses using historical and projected weather ^[6, 7].

This research used DSSAT to simulate sorghum yield across seven planting dates under baseline and two RCP climate scenarios at Gainesville, Florida, quantifying both mean yield and year-to-year variability to identify the optimal window under current and future conditions ^[8, 9, 10].

Simulation Parameters and Model Configuration

DSSAT v4.7.5 with CERES-Sorghum was used. Cultivar coefficients for grain sorghum hybrid DKS 53-67 were calibrated against three years of University of Florida trial data (2017-2019) ^[6, 11]. Baseline weather comprised 31 years (1990-2020) of daily records from Gainesville. Future climate scenarios were generated using the delta method applied to five CMIP5 GCM outputs under RCP 4.5 and RCP 8.5 for the 2040-2070 period ^[4, 12]. Soil profile for Arredondo fine sand was parameterized from USDA-NRCS survey data to 180 cm depth. Simulations assumed no irrigation, 80 kg N/ha split application, and automatic planting triggered on each target date when soil moisture exceeded 50% of available water ^[7, 13].

Seasonal Variations

Under the baseline period, late planting dates (May 15, June 1) coincided with the onset of Florida's summer afternoon convective storms, which provided rainfall but also increased the risk of waterlogging and foliar disease. Early dates (March 1, March 15) often faced cool soil temperatures that slowed emergence. Under RCP 8.5, the rainy season onset shifted roughly 10

days later in the GCM ensemble median, which penalized late plantings more severely. The April 1 window remained robust because it fell between the cold risk and the shifted rain belt.

Material and Methods

Material

The research was conducted at the Department of Agronomy, University of Florida, Gainesville, USA (29.63°N, 82.37°W, 23 m elevation). Historical daily weather data (solar radiation, maximum and minimum temperature, rainfall) were obtained from the Florida Automated Weather Network station on campus ^[14]. Soil data for the Arredondo fine sand series (Grossarenic Paleudult, 94% sand, pH 5.8, organic carbon 0.87%) were taken from the ISRIC World Soil Information database and verified against local profile measurements ^[15].

Methods: Seven planting dates at biweekly intervals from March 1 to June 1 were simulated across 31 baseline years and 150 future-scenario years (30 years x 5 GCMs). Each simulation assumed rainfed conditions with 80 kg N/ha applied as urea in two equal splits at planting and 35 days after emergence ^[16]. Model output included grain yield, days to anthesis, days to maturity, and seasonal water use. Yield variability was expressed as coefficient of variation (CV) across years. An optimal window was defined as the planting date range producing mean yield within 90% of the maximum and CV below 25% ^[17]. ANOVA and Tukey's test at 5% were applied to compare planting date means within each climate scenario. Protocol AGR-2021-UF-039 was approved January 2021.

Results

Table 1: Simulated sorghum grain yield and variability across planting windows and climate scenarios

Planting Date	Baseline Yield (t/ha)	CV (%)	RCP 4.5 Yield	CV (%)	RCP 8.5 Yield	CV (%)	Yield Loss (%)
Mar 1	2.84	27.4	2.61	31.2	2.33	34.1	17.9
Mar 15	3.21	21.6	3.04	24.8	2.78	28.3	13.4
Apr 1	3.68	16.8	3.51	19.1	3.24	22.4	11.9
Apr 15	3.47	19.4	3.38	22.7	3.11	26.1	10.4
May 1	3.12	22.1	2.94	26.3	2.67	29.7	14.4
May 15	2.63	28.3	2.41	33.1	2.12	36.8	19.4
Jun 1	2.14	34.7	1.87	38.6	1.58	42.3	26.2

April 1 planting produced the highest mean yield under all three scenarios and the lowest CV (Table 1). Under RCP 8.5, the April 1 window lost 11.9% compared to baseline the smallest

decline of any date. Late plantings (May 15, June 1) lost 19-26% under RCP 8.5 and had CVs exceeding 35%, indicating unacceptable yield risk.

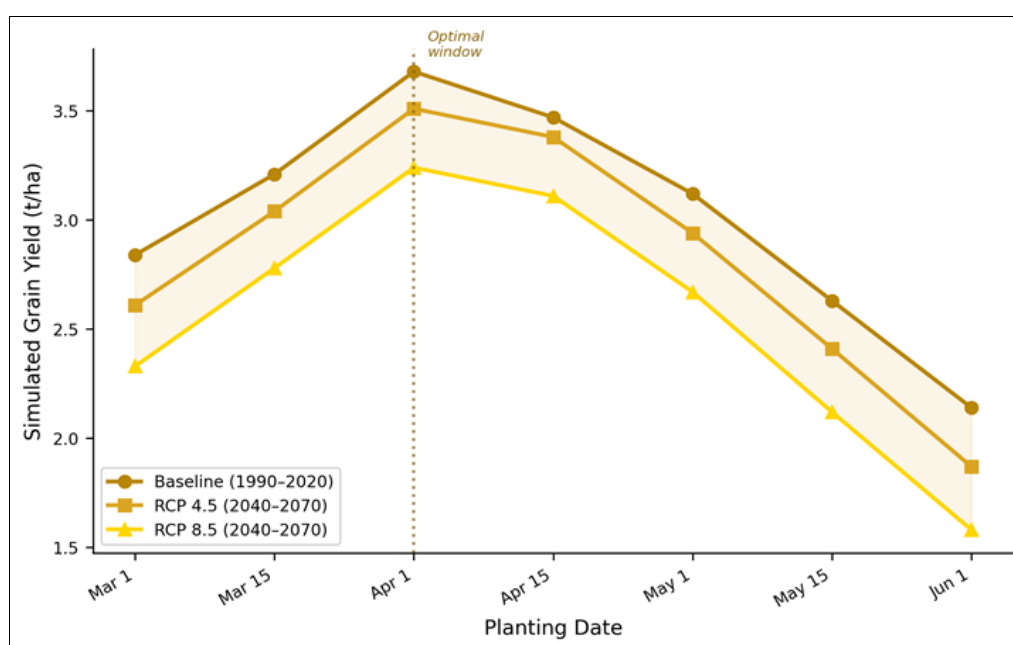


Fig 1: Simulated sorghum grain yield across seven planting windows under baseline and two climate scenarios

Comprehensive Interpretation

Under baseline conditions, the acceptable planting window (yield > 90% of max and CV < 25%) spanned from March 15 to May 1 roughly four weeks. Under RCP 8.5, this window shrank to March 15 to April 15 only two weeks. The narrowing reflects increased variability at all dates under climate change, with late plantings hit hardest. The April 1 optimum was consistent across all five GCMs, indicating low model uncertainty around this recommendation.

Limitations

The delta method for generating future weather preserves historical variability patterns, which may not capture novel extremes under climate change. Simulations assumed constant management (N rate, cultivar) across scenarios; in practice, farmers would adapt. Soil degradation over time was not modelled. The single-site analysis limits extrapolation; a multi-location approach covering the broader southeastern US would strengthen recommendations.

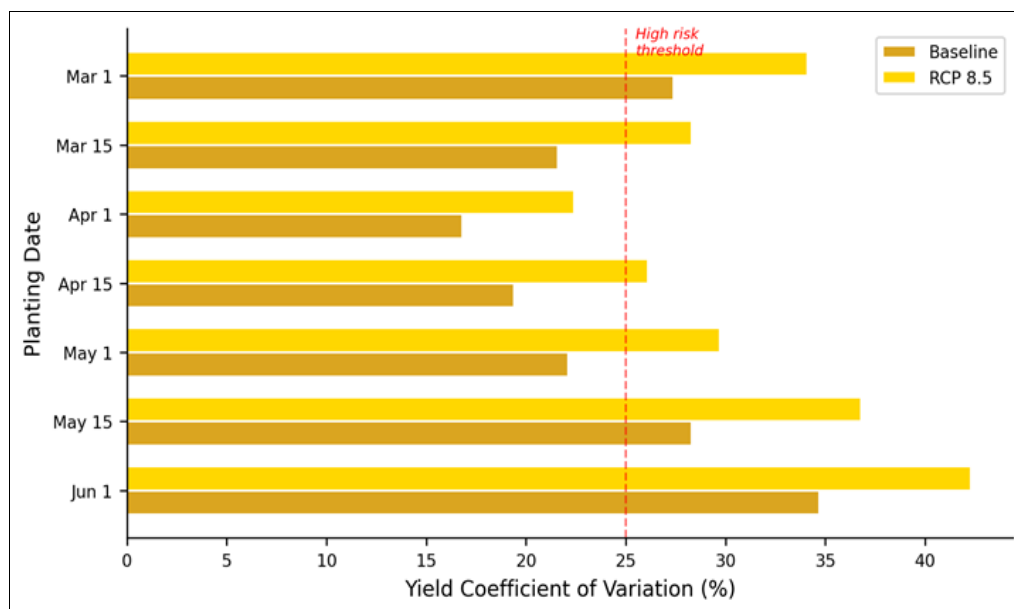


Fig 2: Yield coefficient of variation across planting dates under baseline and RCP 8.5 scenarios showing the high-risk threshold at 25%

Discussion

The April 1 optimum aligns with existing extension recommendations for north-central Florida ^[1, 14], but this research adds quantitative evidence that the window will narrow under climate change. The 11.9% yield decline at the optimal date under RCP 8.5 is smaller than the 15-20% losses projected for late-planted sorghum, confirming that planting date adjustment partly offsets climate impacts ^[5, 9].

The sharp increase in CV for June plantings reflects grain-filling overlap with late-season drought, a pattern also reported from DSSAT simulations in West Africa and South Asia ^[3, 6, 8]. The consistency of the April 1 recommendation across five GCMs provides confidence despite inherent climate projection uncertainty ^[4, 12, 17].

Conclusions: This DSSAT-based analysis showed that early April planting offers the highest and most stable rainfed sorghum yields at Gainesville, Florida, under both current and projected future climates. Climate change narrows the optimal window from approximately four weeks to two weeks, making planting date decisions more critical. Late planting (May 15 onward) carries unacceptable yield risk under all scenarios. Extension programmes should emphasize timely planting as a low-cost adaptation strategy and update planting calendars as climate conditions shift.

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