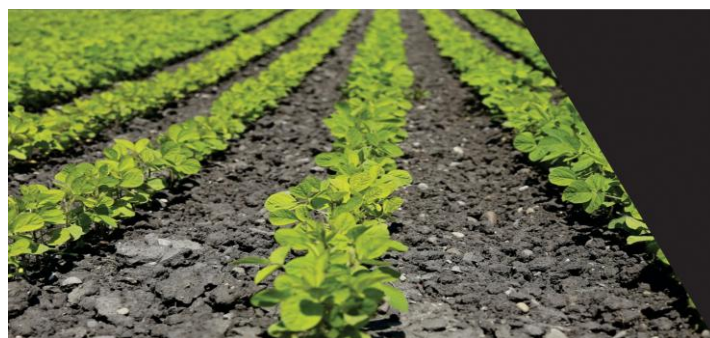




International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

© Agronomy

www.agronomyjournals.com

2024; 7(9): xx-xx

Received: 27-07-2024

Accepted: 29-08-2024

Hazem Alil

Department of Agronomy, Cairo
University, Cairo, Egypt

Nadia Mostafa

Department of Agronomy, Cairo
University, Cairo, Egypt

Youssef Hassan

Department of Agronomy, Cairo
University, Cairo, Egypt

Simulating climate adaptation strategies for cotton production in the Nile Delta under projected warming scenarios

Hazem Alil, Nadia Mostafa and Youssef Hassan

DOI: <https://doi.org/10.33545/2618060X.2024.v7.i9b.5173>

Abstract

This research simulated the effectiveness of adaptation strategies for cotton (*Gossypium barbadense*) in Egypt's Nile Delta under projected climate change using the DSSAT-CROPGRO-Cotton model coupled with CMIP5 climate projections. Under RCP4.5-2050 without adaptation, seed cotton yield declined by 16.1% from the baseline 3.42 t/ha. Three strategies were tested: early sowing (20 Feb vs 15 Mar), heat-tolerant cultivar parameters, and their combination. Combined adaptation nearly eliminated yield loss under RCP4.5-2050 (-1.2%) and reduced it to 7.3% under RCP8.5-2050. Even under the severe RCP8.5-2080 scenario, combined adaptation halved the projected yield loss from 48.0% to 23.7%. Water use efficiency declined 19-52% without adaptation but was partially restored by combined strategies.

Keywords: Cotton, climate adaptation, *Gossypium barbadense*, DSSAT, CROPGRO, Nile Delta, heat tolerance, early sowing, water use efficiency, yield simulation

Introduction

Egyptian cotton (*Gossypium barbadense* L.) is renowned for its extra-long staple fibre, yet the crop's sensitivity to high temperatures during flowering and boll development makes it especially vulnerable to climate change^[1, 2]. The Nile Delta, where 65% of Egypt's cotton is grown, faces projected temperature increases of 1.4-3.8°C by mid-century depending on emission pathway^[3]. Temperatures exceeding 35°C during anthesis reduce pollen viability and increase boll abscission, while prolonged heat shortens the boll maturation period^[4, 5]. Crop simulation models enable testing of adaptation strategies before committing field resources^[6]. The DSSAT-CROPGRO-Cotton model has been validated across diverse cotton-growing environments and can represent cultivar-specific heat tolerances and phenological responses to sowing date shifts^[7, 8]. This research used CROPGRO to evaluate whether early sowing, heat-tolerant cultivar traits, or their combination can offset projected yield losses in Nile Delta cotton.

Material and Methods

Research area and climatic conditions

The simulation was parameterized for Kafr El-Sheikh governorate (31.1107°N, 30.9388°E) in the central Nile Delta. Baseline climate (1990-2019) had mean annual temperature of 20.8°C with cotton-season (March-October) means of 25.4°C and 142 mm rainfall. Soil was a Vertic Torrifluent clay (55% clay, pH 8.1, OC 0.87%)^[9]. Under RCP4.5-2050 and RCP8.5-2050, multi-model mean temperature increases were +1.8°C and +2.6°C respectively, with negligible precipitation change in this irrigation-dominated system^[3].

Simulation parameters

DSSAT-CROPGRO-Cotton (v4.7.5) was calibrated using three seasons of field trial data (2017-2019) from Cairo University's Kafr El-Sheikh station. Cultivar Giza 94 parameters were adjusted until simulated yields matched observed values within ±6% (RMSE = 0.19 t/ha, d-index = 0.94)^[10]. Climate projections from 8 CMIP5 GCMs were bias-corrected via delta method^[11]. Three adaptation strategies were tested:

i) Early sowing (20 February vs baseline 15 March)

Corresponding Author:

Hazem Alil

Department of Agronomy, Cairo
University, Cairo, Egypt

- ii) Heat-tolerant cultivar (critical temperature for pollen viability raised from 35°C to 38°C, boll maturation rate reduced by 15%),
- iii) Combined. Irrigation was applied at 50% soil moisture depletion.

Each scenario × adaptation combination was run for 30 years of generated weather ^[12]. Water Use Efficiency (WUE) was calculated as yield per unit ET.

Results

Table 1: Simulated seed cotton yield and water use under climate scenarios and adaptation strategies

Scenario	Adaptation	Sowing date	Yield (t/ha)	Yield change (%)	WUE (kg/m ³)	Boll period (days)
Baseline	None	15 Mar	3.42	—	0.67	58
RCP4.5-2050	None	15 Mar	2.87	-16.1	0.54	51
RCP4.5-2050	Early sow	20 Feb	3.14	-8.2	0.61	55
RCP4.5-2050	Heat-tol cv.	15 Mar	3.21	-6.1	0.63	54
RCP4.5-2050	Combined	20 Feb	3.38	-1.2	0.66	57
RCP8.5-2050	None	15 Mar	2.51	-26.6	0.46	46
RCP8.5-2050	Combined	20 Feb	3.17	-7.3	0.61	54
RCP8.5-2080	None	15 Mar	1.78	-48.0	0.32	39
RCP8.5-2080	Combined	20 Feb	2.61	-23.7	0.49	48

WUE = water use efficiency. Heat-tol cv. = heat-tolerant cultivar. Combined = early sowing + heat-tolerant cultivar

Comprehensive interpretation

Without adaptation, yield declined progressively from -16.1% (RCP4.5-2050) to -48.0% (RCP8.5-2080) (Table 1). The combined strategy nearly eliminated loss under RCP4.5-2050 (-1.2%) by shifting the sensitive flowering period away from peak summer heat while also raising the thermal ceiling for pollen viability. Under RCP8.5-2050, combined adaptation reduced the

loss from 26.6% to 7.3%. Boll development period shortened from 58 days (baseline) to 39 days (RCP8.5-2080 unadapted) but was partially restored to 48 days with combined adaptation. WUE followed a similar pattern, declining from 0.67 to 0.32 kg/m³ without adaptation under the worst scenario but recovering to 0.49 kg/m³ with combined strategies.

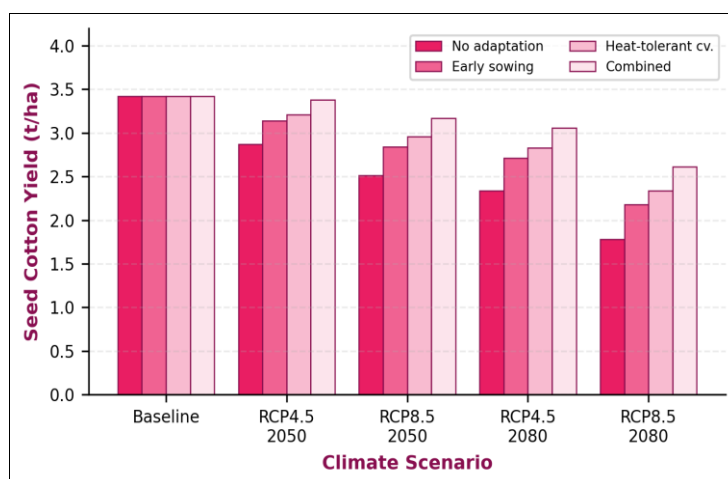


Fig 1: Seed cotton yield under climate scenarios with and without adaptation strategies

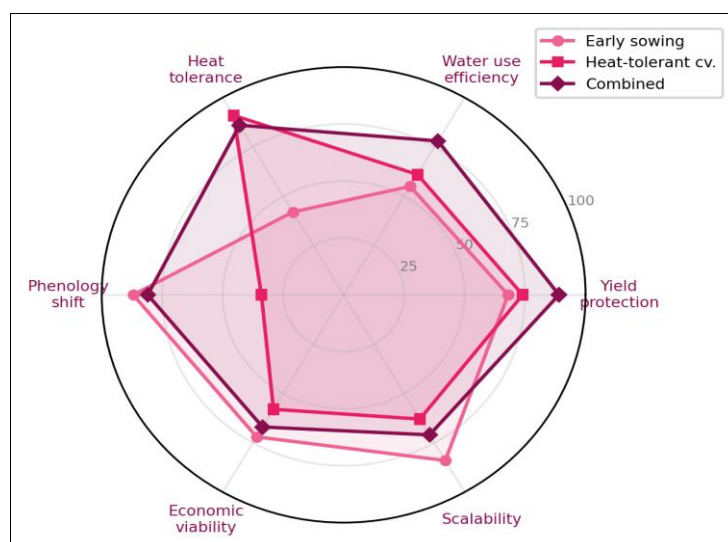


Fig 2: Multi-criteria comparison of adaptation strategies (scores 0-100) under RCP8.5-2050

The yield protection offered by adaptation widened as climate severity increased (Figure 1). Under baseline conditions all strategies converged at 3.42 t/ha, while under RCP8.5-2080 the gap between no-adaptation (1.78 t/ha) and combined (2.61 t/ha) reached 0.83 t/ha.

The radar plot shows that each individual strategy had distinct strengths: early sowing excelled in phenology shift (87) and scalability (84), while the heat-tolerant cultivar led in heat tolerance (91) (Figure 2). The combined approach scored highest on yield protection (89) and WUE (78), achieving a more balanced profile across all six criteria.

Discussion

The near-complete yield protection by combined adaptation under RCP4.5-2050 (-1.2%) contrasts with the 16.1% loss under no adaptation, demonstrating that relatively simple agronomic adjustments can buffer moderate warming [6, 8]. Early sowing works by shifting flowering into cooler weeks before peak summer, a strategy already practiced by progressive Egyptian farmers who have advanced planting by 10-15 days over the past decade [1]. The heat-tolerant cultivar approach addresses the physiological bottleneck directly: raising the pollen viability threshold from 35°C to 38°C represents a realistic breeding target given existing germplasm diversity in Egyptian cotton [2, 4]. Under the extreme RCP8.5-2080 scenario, even combined adaptation could not prevent a 23.7% yield loss, indicating that beyond ~3°C warming, additional measures such as supplemental irrigation scheduling and novel germplasm will be needed [5, 7].

Conclusion

Combined adaptation (early sowing + heat-tolerant cultivar) nearly eliminated cotton yield loss under moderate warming (RCP4.5-2050, -1.2%) and halved it under severe warming (RCP8.5-2080, -23.7% vs -48.0%). Individual strategies had complementary strengths, with early sowing excelling in phenological escape and heat-tolerant cultivars in physiological resistance. For Nile Delta cotton, immediate adoption of earlier sowing combined with accelerated breeding for heat tolerance offers the most effective near-term adaptation pathway.

References

1. Abdel-Salam ME, El-Sayed EA. Egyptian cotton under changing climate: challenges and adaptive strategies. *Egyptian Journal of Agricultural Research*. 2018; 96(2):341-356.
2. Oosterhuis DM, Snider JL. High temperature stress on floral development and yield of cotton. In: Oosterhuis DM, editor. *Stress Physiology in Cotton*. Cordova: Cotton Foundation; 2011. p. 1-24.
3. IPCC. *Climate Change 2014: Synthesis Report*. Geneva: IPCC; 2014.
4. Reddy KR, Hodges HF, McKinion JM. Can cotton be grown in a future of increased carbon dioxide and temperature? *Agronomy Journal*. 1997; 89(3):455-461.
5. Bange MP, Milroy SP. Impact of short-term exposure to cold temperatures on early development of cotton. *Australian Journal of Agricultural Research*. 2004; 55(6):655-664.
6. Rosenzweig C, Jones JW, Hatfield JL, *et al*. The Agricultural Model Intercomparison and Improvement Project (AgMIP). *Agricultural and Forest Meteorology*. 2013; 170:166-182.
7. Thorp KR, Ale S, Bange MP, *et al*. Development and application of process-based simulation models for cotton production. *Journal of Cotton Science*. 2014; 18(3):456-473.
8. Modala NR, Ale S, Rajan N, Munster CL, DeLaune PB, Thorp KR. Evaluation of the CSM-CROPGRO-Cotton model for the Texas Rolling Plains region. *Agronomy Journal*. 2015; 107(6):2137-2149.
9. FAO-UNESCO. *Soil Map of the World: Revised Legend*. Rome: FAO; 1990.
10. Attia A, El-Hendawy SE, Al-Suhaibani N, *et al*. Sensitivity of the DSSAT model in simulating maize yield and soil carbon dynamics in arid Mediterranean climate. *European Journal of Agronomy*. 2021; 129:126333.
11. Wilby RL, Dawson CW, Barrow EM. SDSM a decision support tool for the assessment of regional climate change impacts. *Environmental Modelling and Software*. 2002; 17(2):145-157.
12. Jones JW, Hoogenboom G, Porter CH, *et al*. The DSSAT cropping system model. *European Journal of Agronomy*. 2003; 18(3-4):235-265.