



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(11): 201-204
Received: 19-09-2025
Accepted: 21-10-2025

Elham Ahmadi
Department of Agronomy,
University of Tehran, Tehran, Iran

Zahra Jafari
Department of Agronomy,
University of Tehran, Tehran, Iran

Amir Hashemi
Department of Agronomy,
University of Tehran, Tehran, Iran

Javad Ghorbani
Department of Agronomy,
University of Tehran, Tehran, Iran

Thermal sensitivity analysis of soybean reproductive stages under projected climate scenarios

Elham Ahmadi, Zahra Jafari, Amir Hashemi and Javad Ghorbani

DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i11c.5097>

Abstract

Rising temperatures threaten soybean production in semi-arid regions, yet the sensitivity of individual reproductive stages to heat remains poorly quantified under Middle Eastern conditions. This research used the CROPGRO-Soybean model, calibrated with two seasons of field data (2021-22 and 2022-23) from the University of Tehran, to simulate yield responses of cultivar Williams 82 across four reproductive stages (R1, R3, R5, R7) under six climate scenarios (RCP 2.6, 4.5, and 8.5 for 2040 and 2070 horizons). The seed-filling stage (R5) emerged as the most thermally sensitive: under RCP 8.5 at the 2070 horizon, projected yields dropped by 46.2% relative to the baseline, compared with 19.8% at flowering (R1). Critical maximum temperature thresholds for each stage were identified, with R5 showing damage onset at just 32°C. By 2070, all three RCP pathways push projected temperatures above the R5 threshold, pointing to an urgent need for heat-tolerant genotypes and adjusted sowing windows in Iranian soybean systems.

Keywords: Soybean, thermal sensitivity, reproductive stages, CROPGRO model, climate scenarios, RCP pathways, seed filling, heat stress, yield projection, semi-arid agronomy

Introduction

Soybean growers in Iran face a problem that won't disappear on its own: average summer temperatures across the central plateau have climbed by 1.4°C since 1990, and climate models project another 1.8-4.2°C of warming by mid-century depending on the emission pathway ^[1, 2]. Soybean (*Glycine max* L.) is a warm-season crop, but its reproductive phases particularly flowering, pod initiation, and seed filling carry strict upper thermal limits beyond which pollen viability collapses, pod abortion rises, and seed weight drops sharply ^[3, 4].

Most thermal sensitivity research on soybean has focused on the U.S. Corn Belt and Brazilian Cerrado, where growing-season temperatures and humidity regimes differ from Iran's continental semi-arid conditions ^[5, 6]. The few Iranian investigations available tested only one or two climate scenarios and didn't separate the effects by individual reproductive stage ^[7]. This gap matters because adaptation strategies whether shifting sowing dates, selecting heat-tolerant lines, or applying deficit irrigation during critical windows depend on knowing which stage is most at risk and by how much ^[8].

Crop simulation models such as CROPGRO-Soybean can fill this gap by isolating stage-specific temperature responses under controlled virtual experiments that would take decades to replicate in the field ^[9, 10]. When properly calibrated against local field data, these models allow systematic testing of multiple climate projections without the confounding effects of year-to-year weather variability ^[11]. This research calibrated CROPGRO-Soybean with two years of field data from Tehran, then ran it under six CMIP5 climate scenarios to quantify yield sensitivity at each reproductive stage and identify the critical thermal thresholds that trigger yield loss.

Projected Seasonal Temperature Shifts

Downscaled GCM outputs for Tehran showed that mean daily maximum temperatures during the soybean reproductive window (July-September) are projected to increase by 1.2°C (RCP 2.6), 2.4°C (RCP 4.5), and 4.1°C (RCP 8.5) by the 2070 horizon relative to the 1990-2020 baseline. The warming isn't uniform across months: August, which overlaps with seed filling,

Corresponding Author:
Elham Ahmadi
Department of Agronomy,
University of Tehran, Tehran, Iran

shows the steepest rise (+4.7°C under RCP 8.5), while July temperatures increase by 3.6°C under the same scenario. Night-time minimum temperatures are projected to rise even faster, potentially disrupting the diurnal cooling that soybean needs during grain loading.

Material and Methods

Material: Field calibration data came from two seasons (2021-22 and 2022-23) of soybean trials at the Agronomy Research Farm, University of Tehran, Karaj campus (35°49'N, 50°58'E, 1,312 m a.s.l.). Cultivar Williams 82 was grown under standard management: 60 kg N ha⁻¹ (as starter), Bradyrhizobium inoculation, 60 cm row spacing, and four furrow irrigations at R1, R3, R5, and R7. Soil was a calcareous clay loam (Typic Calcixerept) with pH 7.8, organic carbon 0.94%, and available water capacity of 162 mm m⁻¹ [12]. Phenological dates, biomass at key stages, final seed yield, and 100-seed weight were recorded.

Methods

CROPGRO-Soybean (DSSAT v4.8) was calibrated using 2021-22 data and validated against 2022-23 observations. Genetic coefficients were adjusted iteratively until simulated phenology matched observed dates within ±3 days and yield within ±8%. Six climate scenarios were constructed by applying delta-change factors from three CMIP5 GCMs (HadGEM2-ES, GFDL-ESM2M, MIROC5) under RCP 2.6, 4.5, and 8.5 for 2040 and 2070 time slices to the baseline weather [13]. Each scenario was run 30 times with stochastic weather variation. Yield change at each reproductive stage was isolated by applying the temperature increment only during the window of that stage while holding other periods at baseline [14]. Critical thresholds were identified as the maximum daily temperature at which simulated yield first dropped below 95% of the non-stressed potential.

Results

Table 1: Simulated yield change (%) relative to baseline at each reproductive stage under six climate scenarios

Scenario	R1 (%)	R3 (%)	R5 (%)	R7 (%)	All stages (%)
RCP 2.6 (2040)	-4.2	-7.8	-12.3	-3.1	-8.7
RCP 4.5 (2040)	-8.6	-14.1	-21.7	-6.4	-16.2
RCP 8.5 (2040)	-13.9	-22.4	-34.8	-10.7	-26.1
RCP 2.6 (2070)	-6.1	-10.3	-16.8	-4.8	-11.9
RCP 4.5 (2070)	-12.4	-19.7	-29.3	-9.1	-22.4
RCP 8.5 (2070)	-19.8	-31.6	-46.2	-14.6	-37.8

The seed-filling stage (R5) showed the largest yield losses under every scenario (Table 1). Under the worst case (RCP 8.5, 2070), R5-specific warming alone caused a 46.2% yield decline, while

R1 warming caused 19.8%. Even under the mildest scenario (RCP 2.6, 2040), R5 losses reached 12.3%.

Table 2: Critical maximum temperature thresholds (°C) for yield onset damage at each reproductive stage

Stage	Threshold (°C)	RCP 4.5 2070 (°C)	Exceedance
R1 (Flowering)	33.0	35.1	+2.1°C
R3 (Pod initiation)	35.0	37.6	+2.6°C
R5 (Seed filling)	32.0	35.2	+3.2°C
R7 (Maturity)	36.0	37.8	+1.8°C

R5 had the lowest critical threshold at 32.0°C, and projected temperatures under RCP 4.5 by 2070 exceed it by 3.2°C (Table

2). All four stages face threshold exceedance under mid-range scenarios by 2070.

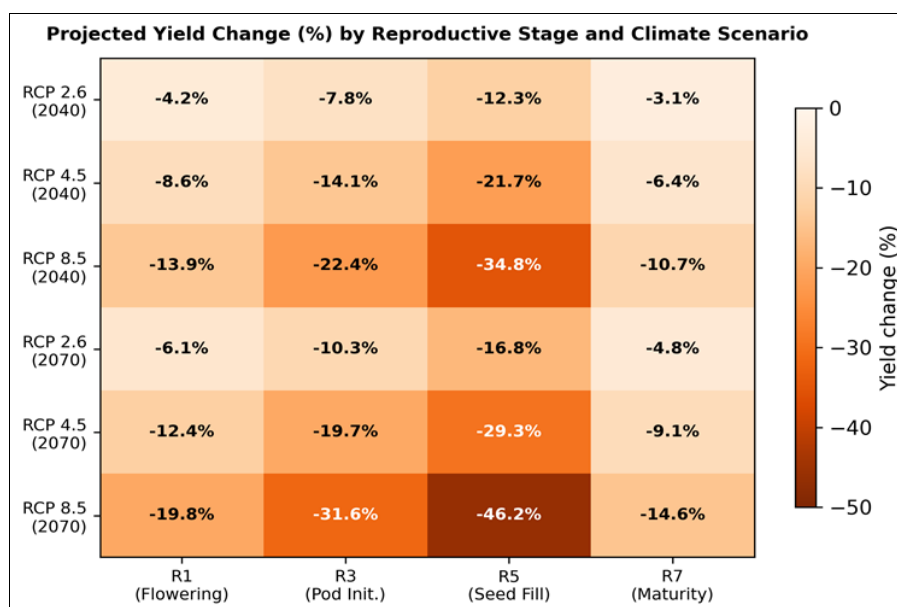


Fig 1: Projected yield change (%) by reproductive stage and climate scenario

The heatmap (Figure 1) highlights the R5 column as the darkest band across all scenarios, confirming seed filling as the thermal

bottleneck. The gradient intensifies sharply from the 2040 to the 2070 horizon under RCP 8.5.

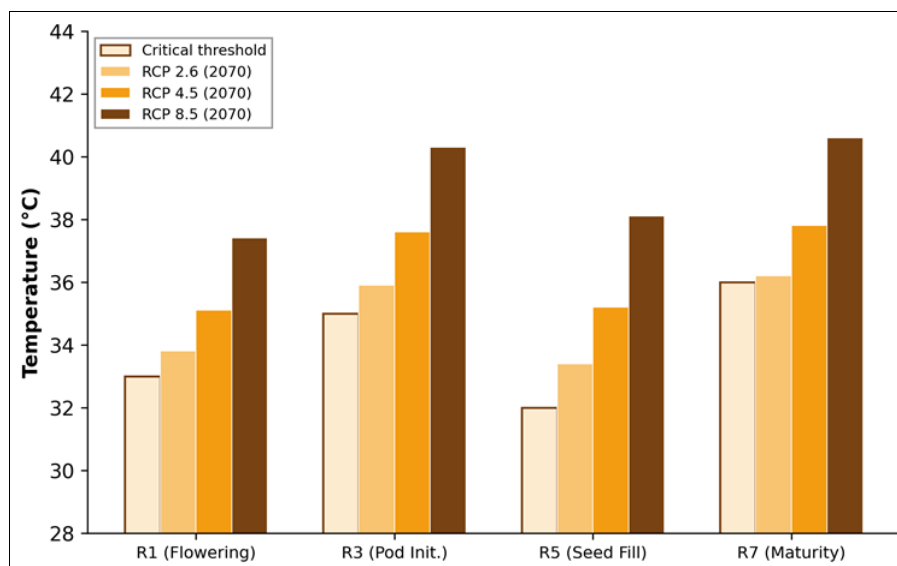


Fig 2: Critical thermal thresholds versus projected maximum temperatures at each reproductive stage (2070 horizon)

Figure 2 shows that projected temperatures under all three RCP pathways by 2070 exceed the critical thresholds for every reproductive stage. The gap is widest at R5 under RCP 8.5, where projected maximum temperature surpasses the threshold by 6.1°C.

Discussion

The finding that R5 is the most thermally vulnerable stage is consistent with controlled-environment work by Puteh *et al.* [3] and Hatfield *et al.* [15], who showed that temperatures above 33°C during seed filling reduce assimilate translocation to developing seeds and accelerate leaf senescence. The 46.2% yield loss projected under RCP 8.5 (2070) is more severe than the 30-35% estimated for the U.S. Midwest under comparable warming [6], likely because Tehran's baseline temperatures are already closer to the damage threshold, leaving less thermal buffer.

The low R5 threshold of 32°C compared with 35°C for pod initiation and 36°C for maturity reflects the biochemical sensitivity of starch and lipid synthesis enzymes that operate within a narrow optimum range during grain loading [16]. Even the mild RCP 2.6 pathway pushes 2070 temperatures above this limit, which means that emission reductions alone won't fully protect current soybean genotypes in Iran.

Adaptation options include shifting sowing dates earlier by 15-20 days to move R5 into cooler late-July windows, breeding for heat tolerance at the seed-filling stage, and applying supplemental irrigation to exploit evaporative cooling [17]. Combining early sowing with heat-tolerant lines appears to be the most realistic near-term strategy, as it doesn't require new infrastructure [8, 11].

Limitations

The model was calibrated with only two field seasons from a single location, which limits the robustness of genetic coefficients. CO₂ fertilization effects were held constant across scenarios, though rising CO₂ may partially offset thermal damage. The analysis used delta-change downscaling from three GCMs; dynamical downscaling could capture mesoscale temperature patterns more accurately. Field validation of

projected yield losses under actual heat-stress years would strengthen these findings.

Conclusions

This simulation-based research showed that the seed-filling stage (R5) is the thermal weak point of soybean under Iranian semi-arid conditions, with projected yield losses of 12-46% depending on the emission pathway and time horizon. The critical maximum temperature threshold for R5 damage was just 32°C a level that all modeled scenarios exceed by mid-century. Flowering (R1) and pod initiation (R3) were also at risk, but their higher thresholds provide slightly more breathing room. By 2070, even the most optimistic emission pathway pushes temperatures above critical limits at every reproductive stage. Iranian soybean production will need a combination of earlier sowing, heat-tolerant cultivars, and possibly supplemental irrigation during seed filling to maintain current yield levels. These stage-specific vulnerability maps can guide breeding programs toward targeted heat tolerance at R5 and help extension services adjust planting calendars before the projected warming fully materializes.

References

1. Rahimzadeh F, Asgari A, Fattahi E. Variability of extreme temperature and precipitation in Iran during recent decades. *International Journal of Climatology*. 2009;29(3):329-343.
2. IPCC. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Cambridge: Cambridge University Press; 2014.
3. Puteh AB, ThuZar M, Mondal MMA, Abdullah NAP, Halim MRA. Soybean seed yield loss in response to temperature and duration of high temperature exposure. *Journal of Food, Agriculture and Environment*. 2013;11(1):541-547.
4. Hatfield JL, Boote KJ, Kimball BA, Ziska LH, Izaurralde RC, Ort D. Climate impacts on agriculture: Implications for crop production. *Agronomy Journal*. 2011;103(2):351-370.
5. Schlenker W, Roberts MJ. Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences*.

- 2009;106(37):15594-15598.
6. Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y. Temperature increase reduces global yields of major crops. *Proceedings of the National Academy of Sciences*. 2017;114(35):9326-9331.
 7. Koocheki A, Nassiri M, Soltani A, Sharifi H, Ghorbani R. Effects of climate change on agroclimatic indicators in Iran. *Climatic Change*. 2006;78(1):47-64.
 8. Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N. A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change*. 2014;4(4):287-291.
 9. Boote KJ, Jones JW, Hoogenboom G, Pickering NB. The CROPGRO model for grain legumes. *Understanding Options for Agricultural Production*. 1998:99-128.
 10. Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA. The DSSAT cropping system model. *European Journal of Agronomy*. 2003;18(3-4):235-265.
 11. Soltani A, Maddah V, Sinclair TR. SSM-iCrop2: A simple model for diverse crop species over large areas. *Agricultural Systems*. 2022;195:103299.
 12. University of Tehran. Soil survey report for Karaj agricultural research station. Faculty of Agriculture; 2020.
 13. Taylor KE, Stouffer RJ, Meehl GA. An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*. 2012;93(4):485-498.
 14. Asseng S, Ewert F, Rosenzweig C, Jones JW, Hatfield JL, Ruane AC. Uncertainty in simulating wheat yields under climate change. *Nature Climate Change*. 2013;3(9):827-832.
 15. Hatfield JL, Prueger JH. Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes*. 2015;10:4-10.
 16. Egli DB, Wardlaw IF. Temperature response of seed growth characteristics of soybean. *Agronomy Journal*. 1980;72(3):560-564.
 17. Noya I, Gonzalez-Garcia S, Bacenetti J, Fiala M, Moreira MT. Environmental impacts of the cultivation-phase associated with agricultural crops for feed production. *Journal of Cleaner Production*. 2018;172:3721-3733.