Academic Communication

ASSESSING THE IMPACTS OF CLIMATE CHANGE ON RAINFED BARLEY YIELD AND WATER DEMAND IN THE LA BALISA SUB-CATCHMENT

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1 Introduction and objectives

The Mediterranean agri-food systems are highly sensitive to the increasing and already observable impacts of climate change (CC), necessitating urgent action to implement practices and policies that enhance water-use efficiency in food production. CC-induced water scarcity, characterised by more frequent and severe droughts, presents significant challenges to agricultural sustainability in this region (Trnka et al., 2011). Rainfed cereal systems, such as barley, are particularly vulnerable, as they depend on variable precipitation patterns that are increasingly disrupted by climate extremes (Lobell et al., 2011). In this context, the AGUAGRADA project (Jiménez-Aguirre et al., 2024) seeks to address these critical issues by analysing agricultural water demand under future CC and adaptation scenarios.

Focusing on the La Balisa sub-catchment (SCAB) in Segovia province, this study leverages AquaCrop, a model developed by the FAO, to assess the impacts of water stress and climate variability on crop yields (Steduto et al., 2009). We specifically focus on barley, a rainfed cereal of critical economic and ecological importance in the study region. This analysis aims to evaluate crop performance under diverse CC scenarios, allowing us to understand crop phenology response to rainfall patterns, temperature, and water stress changes.

Our specific objectives are to assess short- and long-cycle barley yield responses under projected climate scenarios and study the tendencies, considering different efficiency parameters and physiological stress.

2 Methodology

The study area, the SCAB, covers an area of 242 km^2 in the midlands of the Cega-Eresma-Adaja system, belonging to the Duero River Basin. The relief is quite flat (ranging from 747 to 1011 m above sea level), except for some hills within. The soils are mainly characterised by moderate infiltration and are classified as Luvisols, Fluvisols and Cambisols (Nachtergaele et al., 2023). The climate presents extreme dry summers with an average annual precipitation of 427 mm/year (Rivas-Tabares et al., 2019). From 50 km from the city of Segovia, the SCAB reflects typical trends in Castilla y León (Spain).

According to the Map of Crops and Natural Surfaces of Castilla y León (ITACyL, 2022), barley represents 21% of the SCAB surface, being the majority crop, managed mainly in dry land. Starting from a baseline scenario representing the current agricultural and climate situation, the project assesses future water availability for these land uses in SCAB. For this, six global climate models (GCMs) from the IPCC's AR6 (Sixth Assessment Report), scenarios, SSP 4.5 and SSP 8.5, regionalised and evaluated by the Spanish Meteorological Agency (AEMET), are used for the 2015-2099 period. The data are from Nava de la Asunción meteorological station from 2001 to 2014 (observed climate) to calibrate the model.

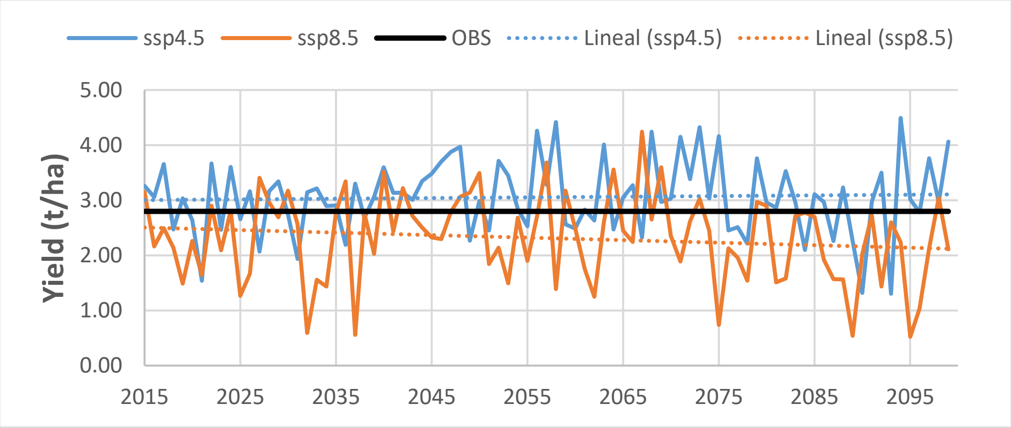
AquaCrop barley's base temperature (calibrated and validated for Ethiopia) was modified from 0 to -5 °C for this project. Previous work by Rivas-Tabares et al. (2022) verifies that the barley present in the SCAB is mainly short-cycle (SC) varieties that have increased their cultivated area against the long-cycle (LC) varieties. The SC varieties have a sowing date of February 25th; meanwhile, the LC ones are on November 25th (ITACyL personal communication). AquaCrop database presents 1296-degree days (DD) for SC lower than for LC (1870 DD).

Based on the average of these six models, different parameters (such as yield, evapotranspiration, water productivity, and days of the cycle) will be evaluated in the near, medium, and long term, analysing different levels of CC impact on this crop at the SCAB.

3 Preliminary results and discussion

The yield (t/ha) outputs for the 2001-2014 simulated period were compared to Segovia yields for the same years (MAPA, 2022), obtaining a regression line with an $R^2 = 0.92$. The yield series showed the same pattern. However, in terms of absolute value, the simulated values were lower than the MAPA average yield. This bias was corrected by adding a constant value in the yield simulations. The first results for scenario 0, without adaptation strategies, show differences in CC impacts for SSP 4.5 and SSP 8.5 (Fig. 1).

Figure 1. Simulated barley yield series from 2015 to 2099: blue line ssp4.5, orange line ssp8.5. The solid black line is the average yield from 2001 to 2014. The dotted lines correspond to the linear regression.



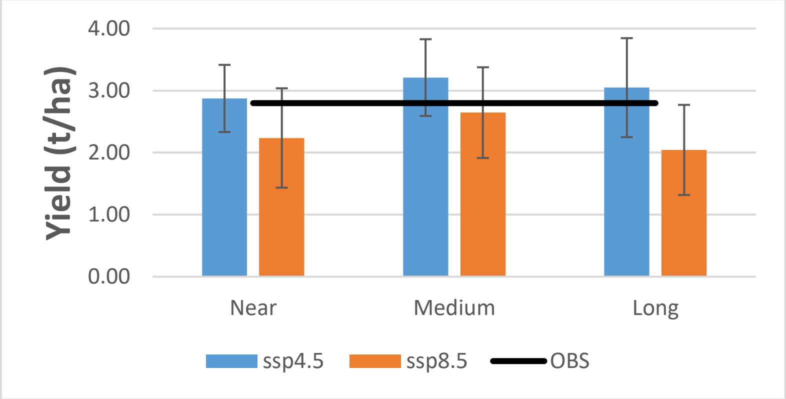
The simulations of barley yield under the two climate projections (SSP4.5 and SSP8.5) reveal notable differences driven by the combined effects of elevated CO_2 concentrations and changing climatic conditions (Table 1, Fig. 2). Under SSP4.5, barley yield is projected to increase by 2%, 13%, and 8% for the near-, medium-, and long-term periods, respectively. This positive effect is primarily attributed to the fertilisation effect of elevated atmospheric CO_2, which enhances photosynthesis in C3 plants like barley. The effect is particularly pronounced in the medium term. Despite the overall yield increases, the simulations also indicate a rise in interannual variability under SSP4.5. This is evidenced by an increase in both the standard deviation of yield (dVEST) and the coefficient of variation (CV), highlighting greater year-to-year fluctuations in yield.

While the fertilisation effect of elevated CO_2 is also observed under SSP8.5, it is overshadowed by the adverse impacts of more extreme climatic conditions. Consequently, barley yield shows a decline of 25%, 6%, and 37% in the near-, medium-, and long-term periods, respectively. This indicates that the benefits of CO_2 fertilisation are insufficient to counteract the adverse effects of higher temperatures, reduced water availability, and other stressors.

Table 1. Descriptive statistics for barley yields (t/ha) in 3 periods: near (2015-2039), medium (2040-2069), and long term (2070-2099)

	SSP 4.5			**SSP 8.5**		
	Near 2015 - 2039	**Medium 2040 - 2069**	**Long 2070 - 2099**	**Near 2015 - 2039**	**Medium 2040 - 2069**	**Long 2070 - 2099**
Average	2.87	3.21	3.05	2.24	2.65	2.04
dVEST	0.54	0.62	0.80	0.80	0.73	0.73
CV (%)	18.84	19.26	26.18	35.84	27.66	35.57

Figure 2. Barley yields average for: near (2015-2039), medium (2040-2069), and long term (2070-2099)



The simulations reveal important patterns for reference evapotranspiration (ET_0), crop cycle length, and water productivity (Fig. 3-4) under the two climate projections (SSP4.5 and SSP8.5). Under SSP4.5 and SSP8.5, ET_0 shows an apparent increase, with a particularly pronounced trend in SSP8.5. This increase in ET_0 reflects higher water demand for crop transpiration and evaporation, driven by rising temperatures and changes in atmospheric conditions. The trend is more significant in SSP8.5 due to the more extreme climate projections.

The simulations indicate a shortening of the barley growth cycle, with a more pronounced trend under SSP8.5. This reduction in cycle length is attributed to higher temperatures, which accelerate plant development and growth, leading to earlier crop maturation. The cycle shortening is more pronounced in the SSP8.5 scenario due to the greater temperature increase associated with this projection.

Figure 3. Simulated evapotranspiration (ET_0) during crop cycle series from 2015 to 2099: blue line ssp4.5, orange line ssp8.5. The solid black line is the ET_0 average from 2001 to 2014. The dotted lines correspond to the linear regression of the simulated series.

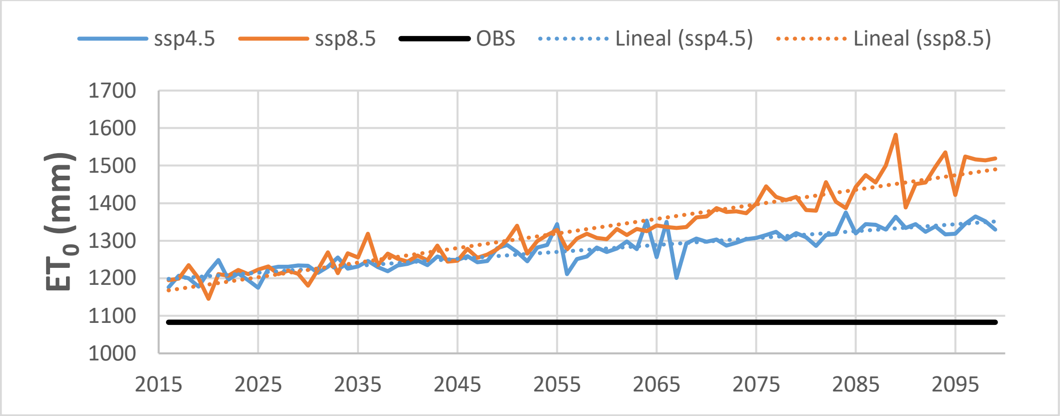
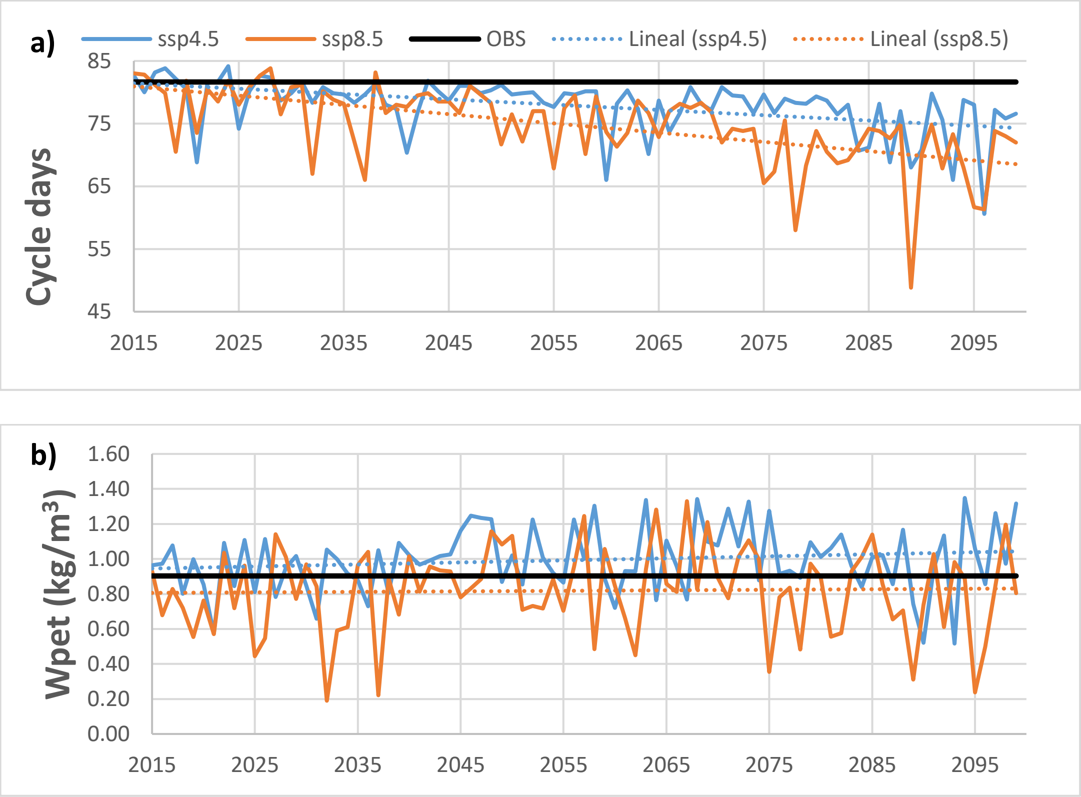


Figure 4. Crop cycle days (a) and Water productivity (Wpet) (b) during crop cycle series from 2015 to 2099: blue line ssp4.5, orange line ssp8.5. The solid black line is the average from 2001 to 2014. The dotted lines correspond to the linear regression of the simulated series.



The water productivity (the ratio of yield to water used) exhibits a pattern similar to yield. In the SSP4.5 scenario, increased yields due to CO_2 fertilisation lead to improved water productivity, although the increased interannual variability complicates this relationship. In SSP8.5, despite the negative impact on yields, water productivity tends to decrease due to the combined stresses of higher temperatures and reduced water availability, which outweigh the benefits of CO_2 fertilisation.

4 Conclusions

CC affects rainfed barley production differently across scenarios. Under SSP4.5, CO_2 fertilisation increases potential yield but more significant interannual variability. In SSP8.5, extreme climatic conditions significantly reduce yields, overshadowing any benefits of CO_2 fertilisation.

Higher temperatures in both scenarios shorten the barley growth cycle, particularly in SSP8.5, leading to incomplete grain filling and reduced yields. Increased reference evapotranspiration (ET_0) under both scenarios highlights greater water demand, with SSP8.5 showing a sharp decline in water productivity due to reduced yields.

Adaptation measures are critical to sustaining barley production under CC. These include developing heat—and drought-tolerant varieties, optimising sowing dates, and adopting water-efficient practices.

5 References

ITACyL. Mapas de cultivos de CyL: versión definitiva 2022. https://www.itacyl.es/-/mapa-de-cultivos-de-cyl-version-definitiva-2022. Last visit 19/12/2024.

Jimenez-Aguirre, M., Galea, C., Garde-Cabellos, S., Ribas-Tabares, D., Soriano, B., Esteve-Bengoechea, P., Blanco-Gutierrez, I., Lisazo, J., Díaz-Ambrona, C. H., Pérez, D., Rodriguez-Sinobas, L., Ruiz-Ramos, M., Bardají, I., and Tarquis, A. M.: Evaluating the demand for water for agricultural use for adaptation to climate change at the subbasin level (AGUAGRADA), EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-17756, https://doi.org/10.5194/egusphere-egu24-17756, 2024.

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. Science, 333(6042), 616–620.

Nachtergaele, F., van Velthuizen, H., Verelst, L., Wiberg, D., Henry, M., Chiozza, F., Yigini, Y., Aksoy, E., Batjes, N., Boateng, E. and Fisher, G., 2023. Harmonized world soil database version 2.0. FAO.

Rivas-Tabares, D., Tarquis, A.M., De Miguel, Á., Gobin, A. and Willaarts, B., 2022. Enhancing LULC scenarios impact assessment in hydrological dynamics using participatory mapping protocols in semiarid regions. Science of the Total Environment, 803, p.149906.

Rivas-Tabares, D., Tarquis, A. M., Willaarts, B., & De Miguel, Á. (2019). An accurate evaluation of water availability in sub-arid Mediterranean watersheds through SWAT: Cega-Eresma-Adaja. Agricultural Water Management, 212, 211-225.

Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. (2009). AquaCrop—The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agronomy Journal, 101(3), 426–437.

Trnka, M., Olesen, J. E., Kersebaum, K. C., et al. (2011). Agroclimatic conditions in Europe under climate change. Global Change Biology, 17(7), 2298–2318.