The impacts of drought in agricultural productivity. An analysis at different scales for the two major rain-fed crops in Spain.

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Introduction

Drought events are considered of great importance in most of Mediterranean climate regions because of the diverse and costly impacts that they cause over the economic and environmental sectors among others. Problems derived by the lack of precipitations are more obvious in semi-arid regions where the absence of these often leads to medium to long-term droughts events. This scenario usually results on a reduced of water supply and water quality which deteriorate the environment and cause severe damages to agriculture. The effects of this natural hazard are more evident in rain-fed crops, for this reason in this work, authors assess the analysis of the impacts of drought over the two more representative rain-fed crops widely cultivated in Spain, wheat and barley.

Data and Methods

In this study two annual datasets of wheat and barley yields have been used from the Spanish Ministry of Agriculture, Fishing, Food and Environment (MAPAMA) at province and agrarian regions scale for the period 1962-2014 and 1993-2015 respectively. The agrarian regions dataset is the result of an aggregate of yield parcels records from the agrarian yield survey ESYRCE for the available period of time. Crop yields series were de-trended to leave out the non-climatic trends (Technology improvements influence the efficiency in agriculture (Lobell & Field, 2007) by fitting a linear regression model, keeping the residuals and adding the average crop yield of each series. The climate monthly data were obtained from *weekly* grids generated by Vicente-Serrano et al., 2017 from daily meteorological data on precipitation, evapotranspiration and maximum and minimum temperature provided by the National Spanish Meteorological Service (AEMET). To provide an assessment of the direct relationship between drought episodes and crop yields diminishing in Spain, seven scalar and multi-scalar drought indices [the Standardized Precipitation and Evapotranspiration Index (SPEI); the Standardized Precipitation Index (SPI); the Palmer Drought Indices (PDSI, Z-Index, PHDI, PMDI) and the Standardized Palmer Drought Index (SPDI)] have been performed at different time scales (1- to 12,18,24-month). The relationship between the de-trended drought indices and crop yields was assessed using Pearson correlation coefficients from a second order polynomial regression model. Since the month of the year when the highest correlation between the drought index and the crop yield was not known a priori, all 14 monthly series for each index were correlated with the annual yields and the highest *r* was kept. August and September were not consider in the analysis. A t-test was performed to compare the slopes and standard error of the regression models of each index to find significant similarities.A Principal Component Analysis (PCA) was run to find similar spatial patterns of response to drought each month at both scales.

Results

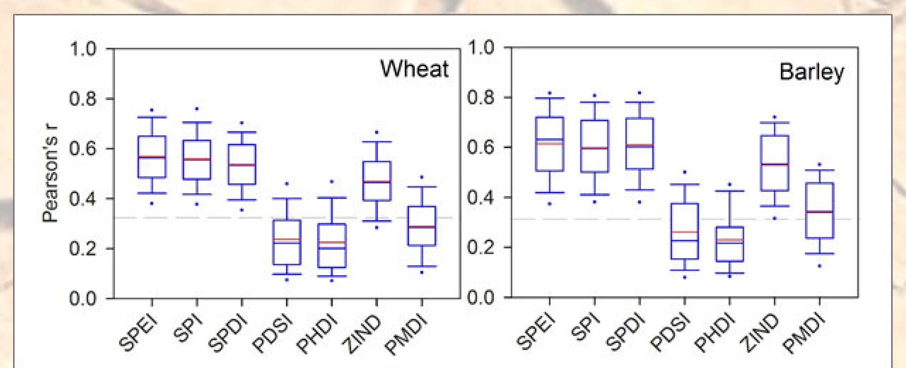

FIGURE 1. Box plots representing the highest Pearson Correlation Coefficients found between wheat (left) and barley (right) yields and the drought indices at regional scale. The solid blue line corresponds to the median, the solid red line to the mean, and dashed grey lines show the limit of significance at p < 0.05.

Independently of the crop type and scale of study, Pearson's r coefficients showed higher and significant values for the multiscalar drought indices SPI, SPEI and SPDI in comparison with the Palmer drought indices (Figures 1 and 2). Among Palmer indices , Z-Index stands out as the better correlated with yields, however ,only the multiscalar indices have been considered for further analysis. Magnitude of correlations indicates that highest values are recorded at regional scale in comparison with the provincial dataset. In both scales, barley yields correlate better with drought indices. SPEI is identified as the index most correlated in each province and region (Figures 3 and 4) with the exception of barley at regional scale (Table 1). Nonetheless, the t-test results –not shown- obtained from the analysis conclude that there are no significant differences between the SPDI (most correlated index with barley yields at regional scale) and SPEI. For this reason, the PCA analysis has been performed using the same drought index, the SPEI. Correlations in the North (Castilla y León and Aragón) present higher values at regional scale corresponding with the areas where wheat is cultivated both in regional as in province scale, while these are found in barley cultivated agrarian central regions of Castilla La Mancha.

Wheat	% Regions	Barley	% Regions	Wheat	% Provinces	Barley	% Provinces
SPEI	36.75	SPEI	35.19	SPEI	58.14	SPEI	69.04
SPDI	33.33	SPDI	44.44	SPDI	13.95	SPDI	9.52
SPI	29.91	SPI	20.37	SPI	27.90	SPI	21.42

TABLE 1. Percentage of counties with significant correlations per index.

In general, the strongest response for multi-scalar drought indices is found when considering the shorter (1 to 3 months) timescales (Figures 7 and 8) disregarding the scale.

Figures 9 and 10 explains the varied patterns of response of the wheat and barley yields drought at the two scale considered. PCA resulted into two different general patterns of response in the different crops. Overall, the sensitivity to drought is major during Spring as seen in the PC-Loadings, this result is more evident at regional scale where the areas of the North of Spain conform the eminently winter cereal region while the Central and South show that drought is not the only mechanism that explain yields variations (Figure 11).

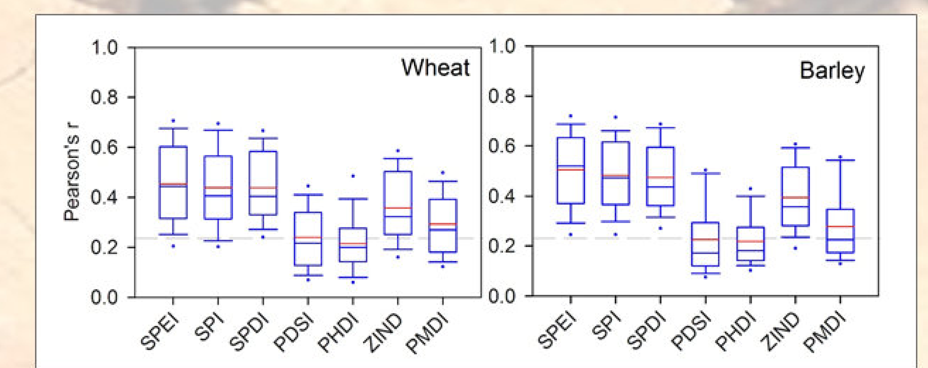

FIGURE 2. Box plots representing the highest Pearson Correlation Coefficients found between crop yields and the drought indices at province scale. The solid blue line corresponds to the median, the solid red line to the mean, and dashed grey lines show the limit of significance at p < 0.05.

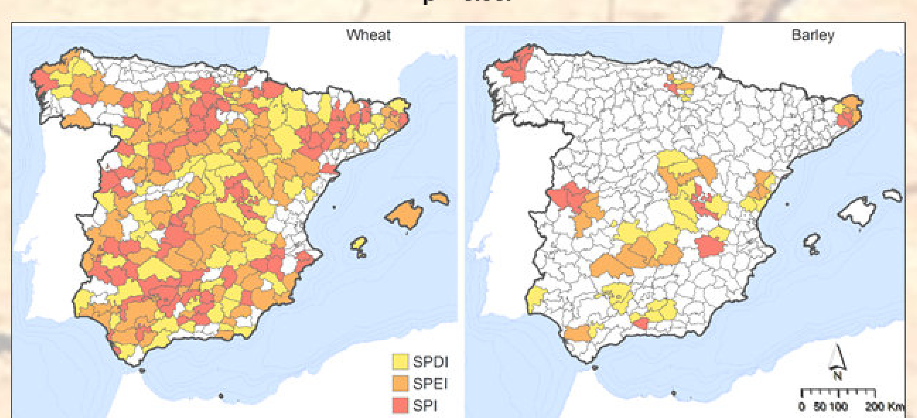

FIGURE 3. Spatial distribution of the drought indices which present the highest correlations with wheat (left) and barley (right) at regional scale.

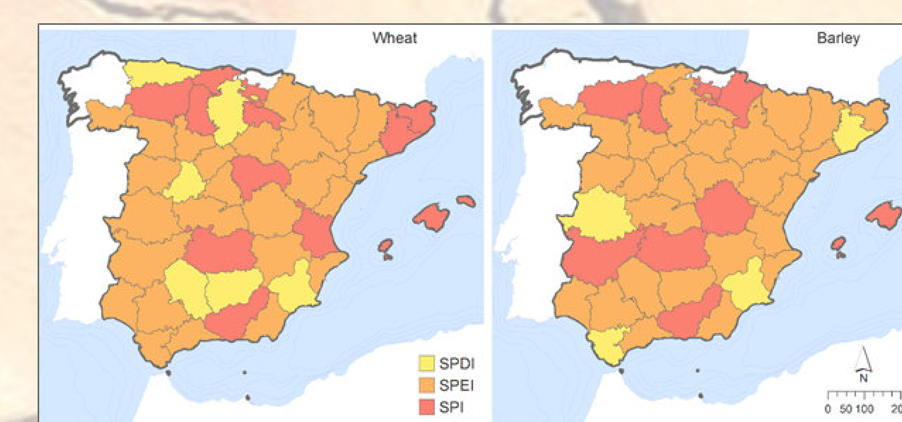

FIGURE 4. Spatial distribution of the drought indices which present the highest correlations with wheat (left) and barley (right) at province scale.

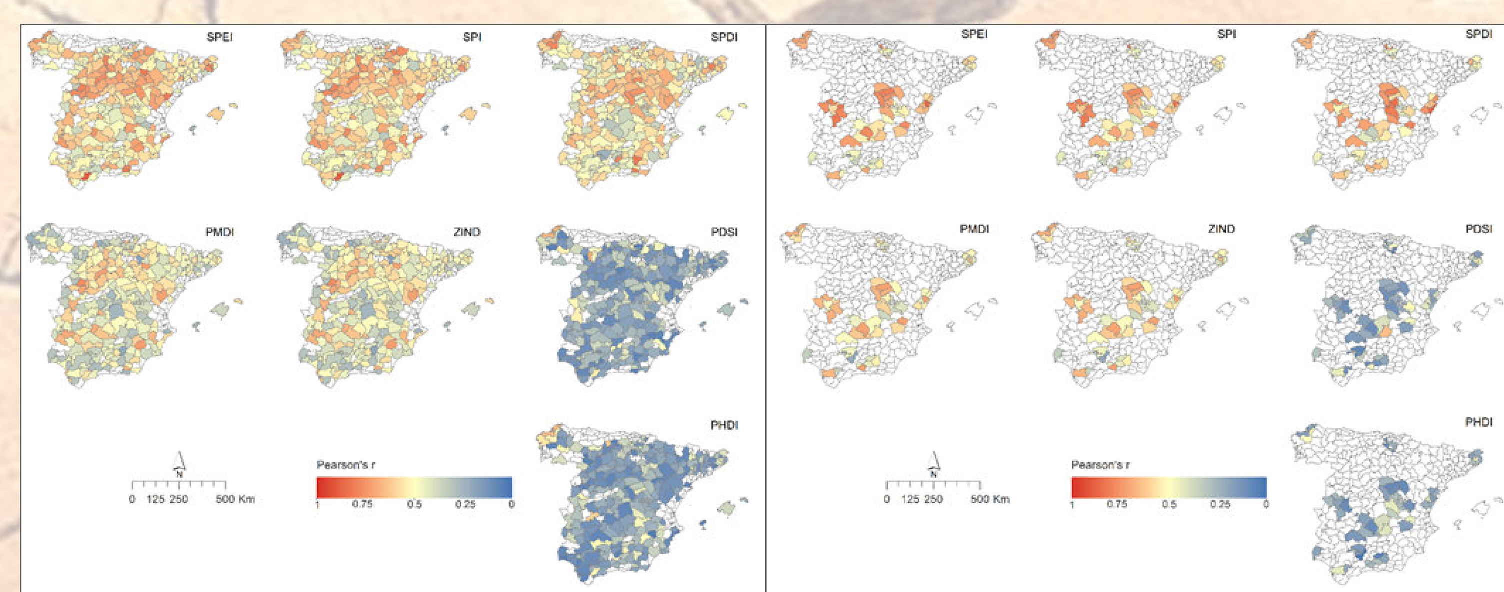

FIGURE 5. Spatial distribution of the highest Pearson correlation coefficients obtained for the wheat (left) and barley (right) yields and drought indices independently of the time scale at regional scale.

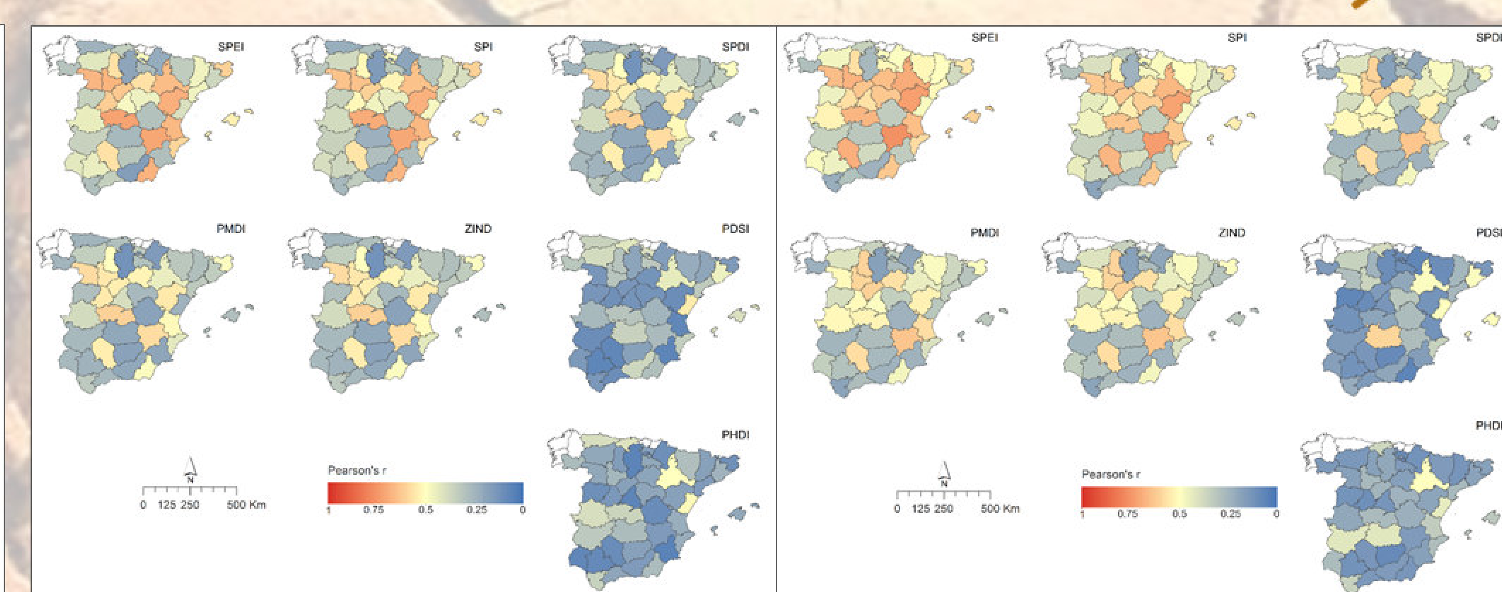

FIGURE 6. Spatial distribution of the highest Pearson correlation coefficients obtained for the wheat (left) and barley (right) yields and drought indices independently of the time scale at province scale.

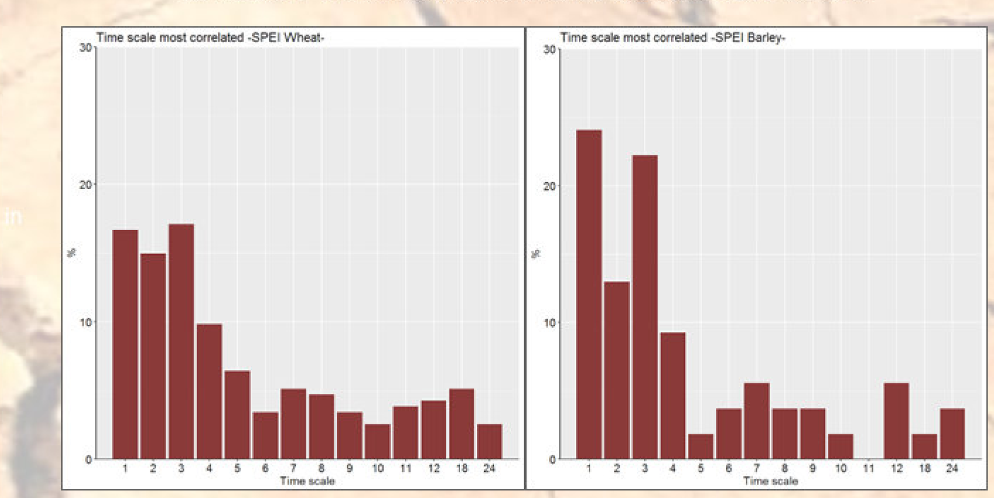

FIGURE 7. Percentage of agrarian regions and timescale at which the maximum correlation is found for wheat (left) and barley (right) yields at regional scale.

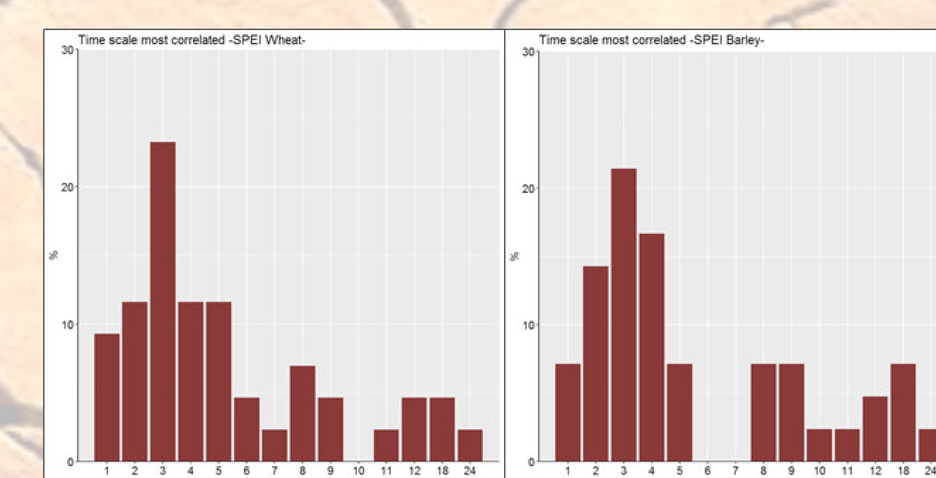

FIGURE 8. Percentage of agrarian regions and timescale at which the maximum correlation is found for wheat (left) and barley (right) yields at province scale.

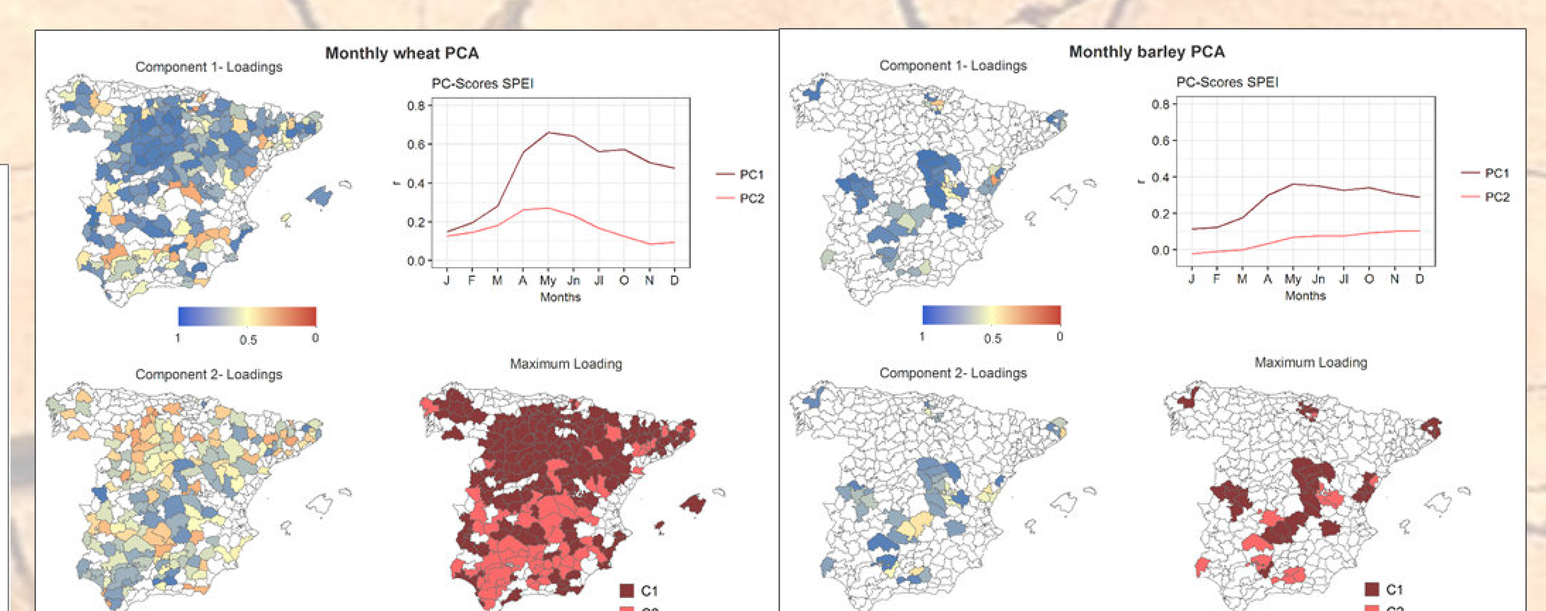

FIGURE 9. PC-Loadings, PC-Scores and Maximum loading rule from the PCA of monthly maximum correlation coefficients found independently of the time scale between SPEI and wheat (left) and barley (right) yields at regional scale. PC-Loadings and Maximum loading show significant correlations at p<0.05.

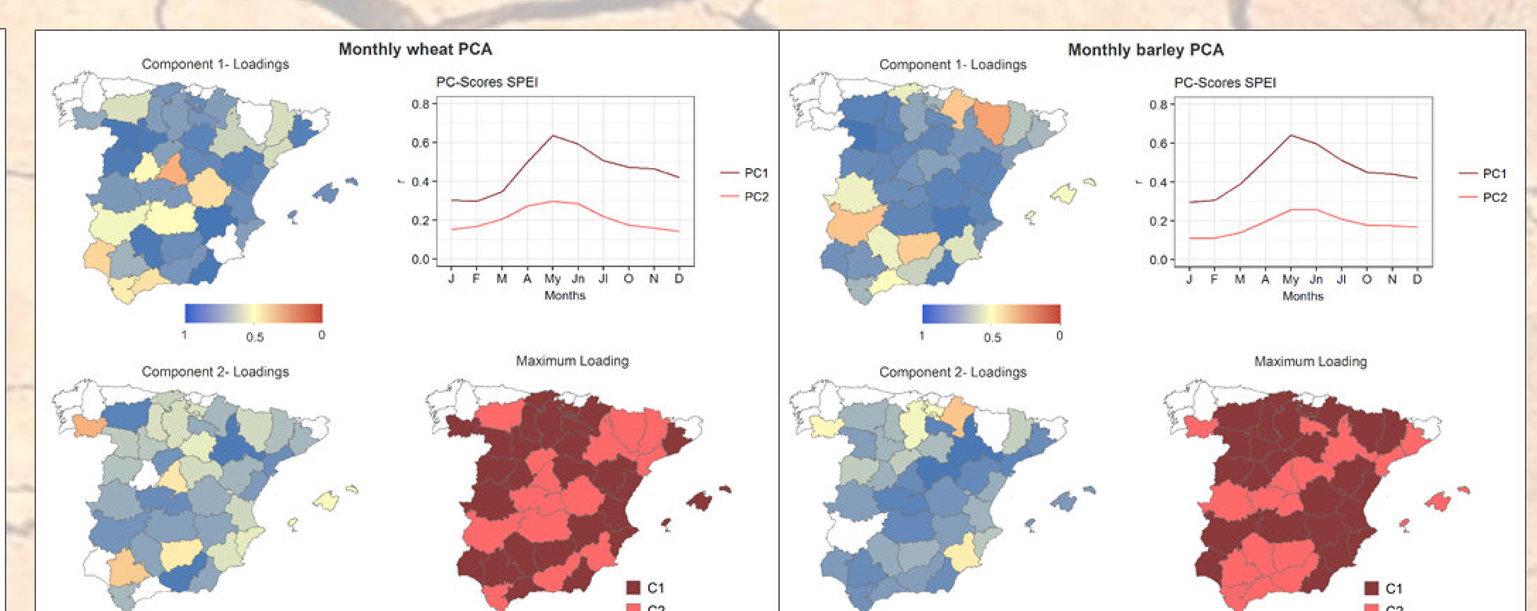

FIGURE 10. PC-Loadings, PC-Scores and Maximum loading rule from the PCA of monthly maximum correlation coefficients found independently of the time scale between SPEI and wheat (left) and barley (right) yields at province scale. PC-Loadings and Maximum loading show significant correlations at p<0.05.

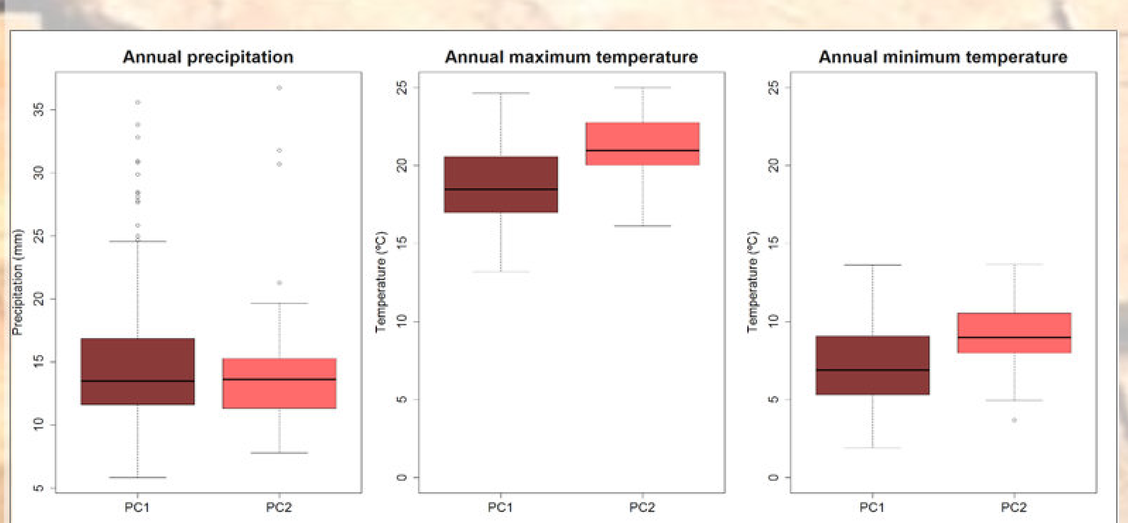

FIGURE 11. Statistical distribution of maximum and minimum temperatura and annual precipitation corresponding to the different groups of response of the annual wheat crop yields the components extracted in the PCA.

Take home messages

- Multiscalar drought indices outperform uniscalar drought indices for monitoring the impact of drought on crop yields.
- Shorter drought time-scales (1 to 3 months) are better at identifying drought impacts on crop yields.
- The relationship between crop yields and drought is better explained when performing the analysis at regional scale, even though the spatial and temporal availability of the data at regional scale is limited.
- There are significant temporal and spatial differences in the crop yield response to SPEI among the two type of crops considered.

Bibliography:
Lobell, D. B., & Field, C. B. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. Environmental Research Letters, 2(1), 14002.
Vicente-Serrano, S. M., Tomas-Burguera, M., Beguería, S., Reig, F., Latorre, B., Peña-Gallardo, M., González-Hidalgo, J. C. (2017). A High Resolution Dataset of Drought Indices for Spain. Data, 2(3), 22.

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