Drought: Research and Science-Policy Interfacing – Andreu et al. (Eds)

Drought effects on rainfed agriculture using standardized indices: A case study in SE Spain

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ABSTRACT: Multiscale relationships between different drought indices have been explored in two areas dominated by herbaceous crops and vineyards in SE Spain. SPI and SPEI values were computed as meteorological drought indices, while raw values of the NDVI from MODIS-Aqua, their anomalies and standardized values at 1, 3, 6, 9 and 12-month timescales were used as agricultural drought indices. At the end of the growing season herbaceous crops showed more reliance on the accumulated rainfall inputs during the agricultural year than on the meteorological water balance, whereas vineyards were less sensitive to rainfall inputs and drought conditions. Overall, SPI was found a better predictor of agronomical indices. Highest multiscale correlations for herbaceous crops were found at short timescales (SVI1 vs SPI6), while in vineyards were found at medium timescales (SVI3 and SPI9). Results confirm that the impact of meteorological drought has a larger delay in vineyards than in herbaceous crops. Drought monitoring systems should include algorithms that are able to distinguish among plant functional types in order to anticipate adequately to the adverse effects of meteorological droughts on rainfed agriculture.

1 INTRODUCTION

Adaptation of Mediterranean agriculture to a changing climate with more recurrent and severe drought periods requires reliable Drought Early Warning Systems (DEWS) that are able to alert on the onset of droughts and to forecast their potential impacts on agriculture. Agricultural droughts occur when rainfall inputs and soil moisture are inadequate to support healthy crop growth conditions resulting in crop stress and losses of yield (Mishra & Singh, 2010). Understanding the linkages between meteorological and the agricultural drought, is critical for understanding the effects of water scarcity on crop production (Vicente-Serrano et al. 2006) and for triggering actions to prevent and mitigate their effects timely (Hayes et al., 2011).

Drought Indices (DI) are quantitative measures useful for monitoring droughts and assessing their effects (Mishra & Singh, 2010; Nuñez et al. 2014; Zargar et al. 2011). Among the indices more widely used in drought science and planning stand out those belonging to the family of standardized indices (SDI). The Standardized Precipitation Index (SPI) (Guttman, 1999) is by far the most adopted one and its use is recommended by the World Meteorological Organization as "the standard index" for monitoring meteorological droughts (Hayes et al. 2011). Other SDIs as the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010) have been proposed as a more accurate measurement of the soil water balance and dynamics, especially in climate regimes, as the Mediterranean, in which rainfall and potential evapotranspiration dynamics are out of phase.

Satellite-based Vegetation Indices (VI) as the Normalized Difference Vegetation Index (NDVI), have been widely used in drought monitoring assessments (Zargar et al. 2011). They have been proven to be well correlated with the total content of aboveground green biomass (commonly known as greenness) and therefore with the health status of vegetation. Different VIs have been included in a large number of DEWS (Brown et al. 2008; Kogan, 1990; Svoboda et al. 2010). Also Standardized VI (SVI) have been used to monitor and characterized agricultural droughts (Peters et al. 2002).

In this study, we explore the effect that the type of cropping system has on the multiscale relationships between meteorological and agricultural DIs in a semiarid Mediterranean region in SE Spain. Two main questions guide our study: a) Which greenness traits (raw, anomalies or standardized values) are more related with meteorological drought indices?, and b) What are the relationships between SVI and meteorological indices at different timescales?

2 METHODS

2.1 *Setting framework*

The study area is framed in the Segura River Basin in SE Spain (Fig. 1). Climate in the region is dominantly semiarid with a mean annual precipitation of 381 mm/year, and an interannual coefficient of variation of 25% (1940–2009 period). Data analysis was focused on two different areas dominated by herbaceous crops and vineyards located at the center and north of the basin, respectively.

2.2 *Meteorological drought indices*

SPI and SPIE were computed for each area using monthly values of rainfall and average temperature recorded at two meteorological stations belonging to the SIAM agrometeorological network. All meteorological data was collected from January 2000 to July 2014. SPI and SPIE values at 1, 3, 6, 9 and 12-month timescales (SPI1, SPI3, SPI6, SPI9 and SPI12) were retrieved following the standard procedures described in literature. The identification and classification of the drought periods derived for both agrometeorological stations was carried out using SPI9 values in close agreement with the length of the growing-vegetation period in the region. The run method and the drought classes stated by Agnew (2000) were used for this analysis.

2.3 *Agricultural drought indices*

The NDVI from July-2002 to August-2014 was extracted from the MYD13A2 product of MODIS-Aqua (tile h17v5) and used as an index of vegetation-crop health. The MYD13A2 dataset consists of 16-day Maximum Composite Values with a 1 km^2 spatial resolution.

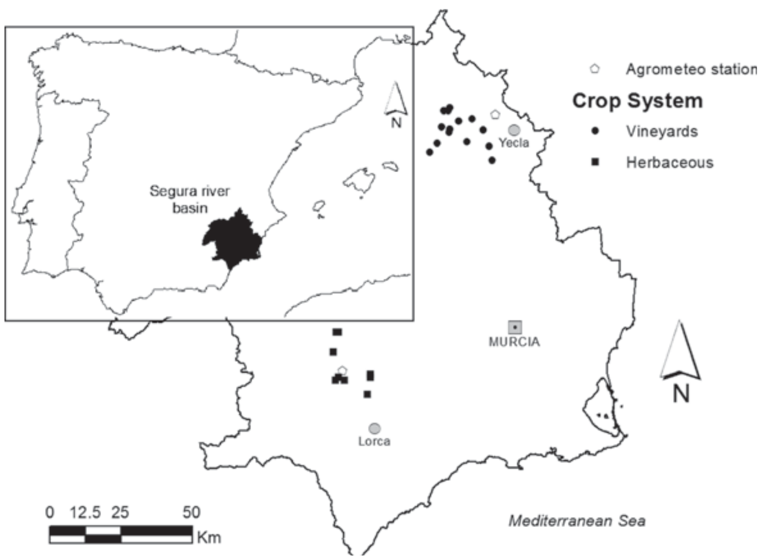

Figure 1. Study area and locations of the sampled set of herbaceous and vineyard areas.

Before the analysis, low-quality values were neglected from the raw spatial dataset using the quality layer provided by the product and a user-defined quality-matrix.

NDVI values time series were extracted for a set of pixels dominated by herbaceous crops (n = 10) and vineyards (n = 15) using the land cover map provided by the SIOSE2005 project (http://www.siose.es). In order to obtain a representative NDVI signature for each cropping system median time series were derived from the 16-day NDVI single time series and finally averaged at the monthly time resolution. Three types of indices were computed and analyzed: a) single monthly anomalies, i.e. the monthly deviation of the observed NDVI values against its corresponding average value in the September-2002–August-2014 period; b) the accumulated anomaly of NDVI (AANDVI) along the agrohydrological year (September–August) in absolute and relative (regarding the average year profile) terms; c) the SVI retrieved at 1, 3, 6, 9 and 12 monthly scales.

3 RESULTS

Greenness trajectories of herbaceous and vineyards differ greatly (Fig. 2). As expected, the seasonal amplitude and the interannual variability in herbaceous was much more marked than in woody crops, although both cropping systems reached their maximum greenness in April–May. Based on these results we consider a 9-month vegetation-growing period starting in September.

Several drought episodes have been identified and characterized in the region during the study period (Table 1, Fig. 3). A drought run starts when SPI < –0.84 and ends when SPI gets positive values. Severity, magnitude and intensity (dimensionless) were computed as the accumulated, average and minimum values of SPI in their respective runs.

Herbaceous crops and vineyards showed different responses to droughts (Table 2). For herbaceous crops, NDVI_May and SVI values were strongly correlated with SPI9 and SPEI9 values computed at May (r > 0.85). In vineyards relationships were moderate with SPI, but very weak with SPIE which may suggest a higher reliance of vineyards on rainfall inputs than on the local water balance. In our case study, SPEI did not increase the predictive skill of SPI in explaining the variance observed for the different vegetation traits.

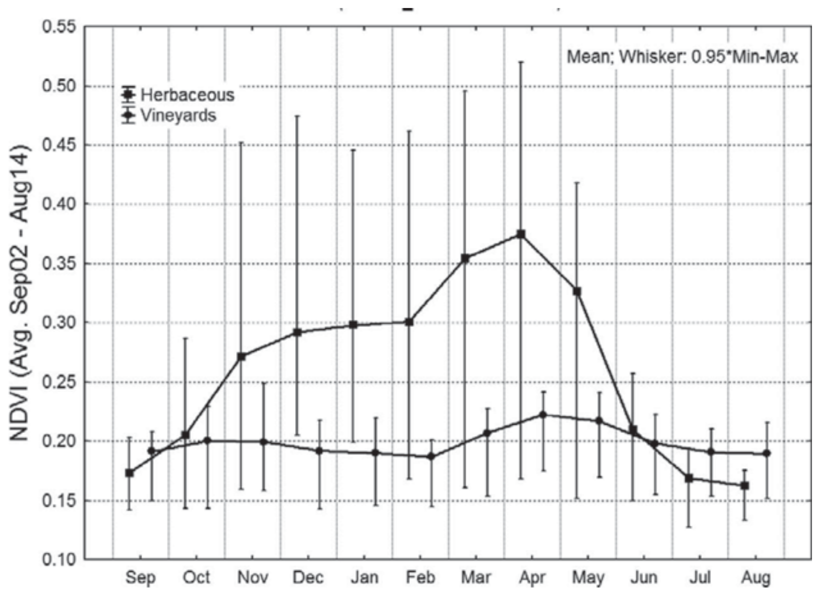

Figure 2. Average seasonal dynamics and interannual variability observed in the Jul-2002–Aug-2014 period.

Overall, agricultural drought indices observed in herbaceous crops had a better relationship with meteorological indices than those in woody crops (Table 3). When cross-correlations among the standardized indexes were performed, deviations of 3-month accumulated greenness from the average (SVI3) were best correlated with the rainfall drought dynamics observed in the antecedent 6-months with a time lag of 1 month (data not shown) in herbaceous crops. In vineyards the highest correlations were found with antecedent rainfall accumulated over a longer time window (9–12-months) (Table 3).

Table 1. Drought periods in the study area. Drought classes are: 0: No drought (SPI < −0.84); -: Moderate (−0.84 < SPI < −1.28); --: Severe (−1.28 < SPI < −1.65); ---: Extreme (SPI < −1.65).

Initiation time	Duration (month)	Severity	Magnitude	Intensity
Lorca ('herbaceous')				
Sep-2001	3	−1.11	−0.28 (0)	−0.85 (-)
Jan-2005	16	−14.43	−0.90 (-)	−1.80 (--)
Jun-2006	5	−4.10	−0.82 (-)	−1.15 (-)
Aug-2013	ongoing	−31.00	−2.38 (---)	−2.90 (---)
Jumilla ('vineyards')				
Sep-2000	9	−6.39	−0.71 (ND)	−1.70 (---)
Jan-2005	20	−23.76	−1.19 (-)	−2.19 (---)
Aug-2011	15	−14.22	−0.95 (-)	−2.11 (---)
Dec-2013	ongoing	−16.06	−1.78 (---)	−2.20 (---)

Table 2. Correlations (Pearson product-moment correlation coefficient, r) between meteorological and satellite-based vegetation indices computed for May and representative for the end of the vegetation growing period. AANDVI refers to accumulated NDVI from the start of the growing period (September), SVI(X) refers to Standardized Vegetation Index for different timescales X.

Variable	NDVI_May	AANDVI_May	SVI(X)_May
Herbaceous			
SPI9_May	0.85	0.71	0.86 (X = 3)
SPEI9_May	0.84	0.81	0.88 (X = 3)
Vineyards			
SPI9_May	0.71	0.60	0.72 (X = 3)
SPEI9_May	0.33	0.17	0.33 (X = 1)

Table 3. Multiscale correlations (r) observed between SPI and SVI values (lag timestep = 0) in herbaceous and vineyards. Maximum correlation coefficients by cropping system are underlined.

Variable	SVI1	SVI3	SVI6	SVI9	SVI12
Herbaceous					
SPI1	0.18				
SPI3	0.44	0.29			
SPI6	<u>0.62</u>	0.57	0.45		
SPI9	0.56	0.56	0.55	0.50	
SPI12	0.50	0.48	0.51	0.55	0.39
Vineyards					
SPI1	0.26				
SPI3	0.48	0.38			
SPI6	0.67	0.63	0.50		
SPI9	0.72	<u>0.73</u>	0.67	0.56	
SPI12	0.70	0.73	0.73	0.68	0.58

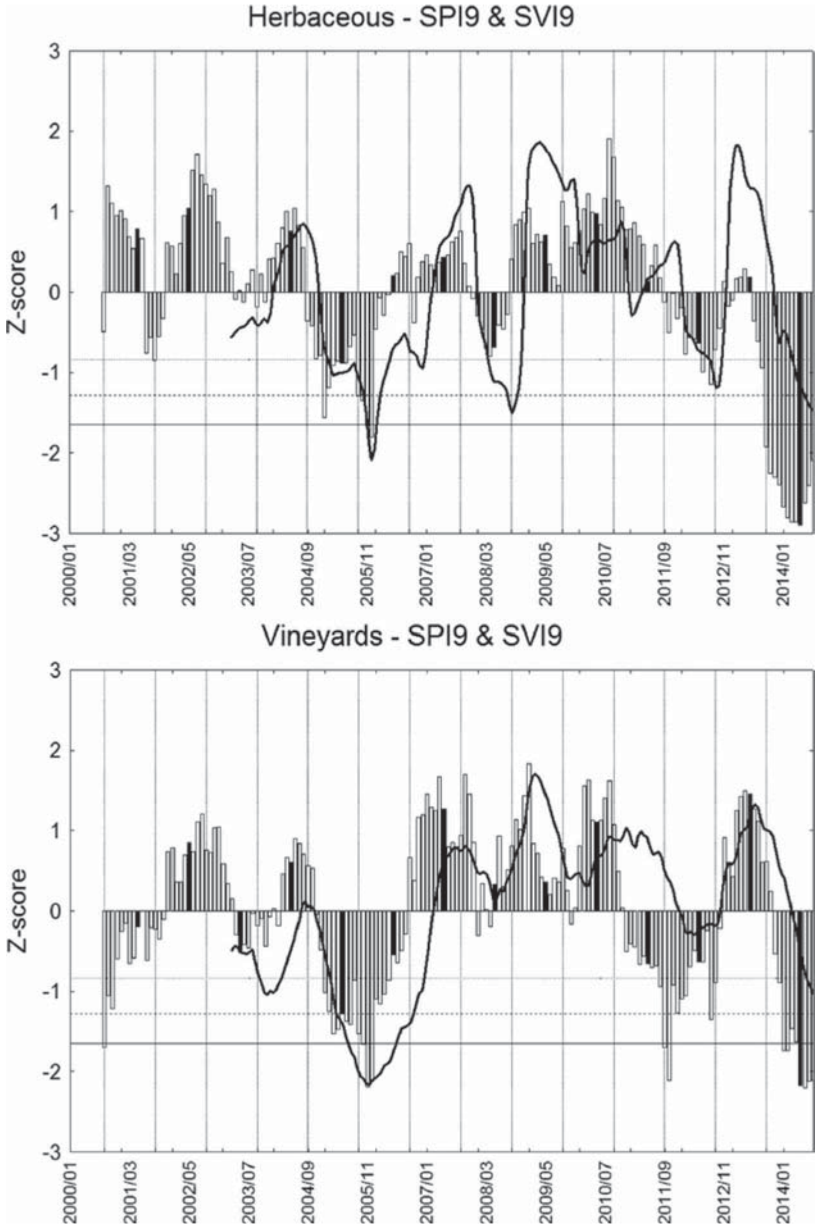

Figure 3. Seasonal dynamics of SPI9 (bars) and SVI9 (line) in different cropping systems in SE Spain. Black bars correspond to May values (end of the vegetation-growing period).

4 CONCLUSIONS

Herbaceous and woody (vineyards) crops showed different sensitivity and vulnerability to droughts in a semiarid area in SE Spain. Results confirm that the impact of meteorological drought has a larger delay in vineyards than in herbaceous crops. SPI values in the short-term (3-months) were strongly related with the greenness dynamics of herbaceous crops, but much less in vineyards. The productivity of vineyards is nevertheless more tied to the antecedent rainfall accumulated at medium-term time scales (9–12 months).

Overall, the inclusion of a water balance-related index as SPIE did not increase the performance of SPI to predict agricultural drought dynamics in both cropping systems. Drought monitoring systems should include algorithms that are able to characterize plant functional types in order to anticipate properly to the adverse effects of meteorological droughts on rainfed agriculture.

ACKNOWLEDGEMENTS

This work has been carried out within the GEISEQ (Gestión Integral de Sequías) project supported by FutureWater, and the European Social Fund through a Torres Quevedo research contract (PTQ-12-05412) granted by the Spanish Ministry of Economy and Innovation.

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