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Development of a drought index for vine water management under Mediterranean climate

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Climate change is significantly exposing Mediterranean viticulture to growing risks, particularly those associated with the frequency and duration of water deficit episodes. Significant inter-annual and inter-seasonal variability in these water constraints has been observed, making difficult to optimize adaptation techniques such as minimal irrigation or "dry farming"[1]. The quality of meteorological data is essential for calculating revised drought indicators that are useful for analyzing crop cycles.

Reference evapotranspiration (ETo)

Wate climatic demand is generally quantified using reference evapotranspiration (ETo). The FAO-56 Penman–Monteith equation is considered the international standard method for calculating ETo. ETo is determined from an energy and aerodynamic balance for a reference crop (short, healthy, well-watered grass). The calculation combines net radiation, air temperature, relative humidity, and wind speed[2]. This method is robust, scientifically validated, and applicable across a wide range of climates. However, it requires complete, high-quality meteorological data, since estimated meteorological data can significantly increase the uncertainty in the ETo value.

ETo calculated using the Penman–Monteith method can also be supplied directly, as is the case with the Météo France weather station networks or private providers. Figure 1 shows the variation in the cumulative daily ETo in Perpignan, Roussillon, France, over three consecutive years based on three data sources. The data supplied by Météo France and the private provider are highly correlated with those calculated using the FAO-56 method ($R^2 > 0.9$). However, compared with the FAO-56 method, the data supplied by "Météo France" are on average 12 % higher, while those from the private provider are 22 % lower. This example illustrates that the approximations made in calculating intermediate parameters in the Penman–Monteith method can lead to substantial variations. It is therefore necessary to use a single data source for ETo, particularly when calculating drought indicators.

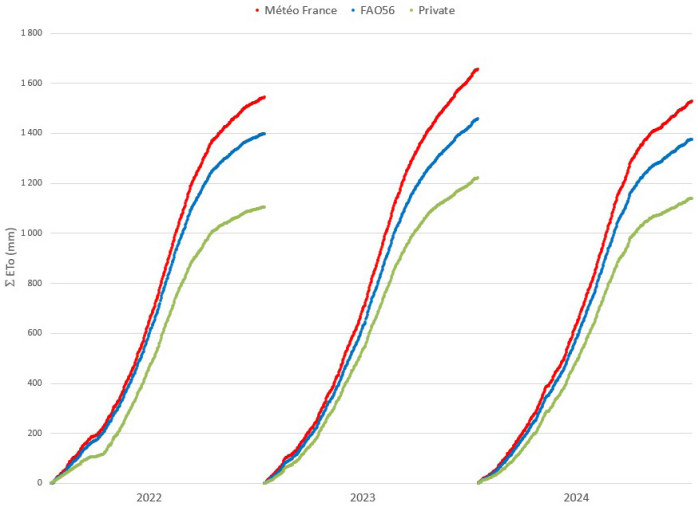


FIGURE 1. Cumulative reference evapotranspiration in Perpignan in 2022, 2023, and 2024, calculated using the FAO-56 Penman–Monteith method (in blue) and supplied by Météo France (in red) and a private provider (in green).

Standardized Precipitation-Evapotranspiration Index (SPEI)

The *Standardized Precipitation-Evapotranspiration Index* (SPEI) is a drought indicator developed to better understand the effects of climate change. Unlike indices based solely on precipitation, the SPEI incorporates reference evapotranspiration (ETo). The method is based on calculating the climatic balance: the difference between precipitation (P) and reference evapotranspiration (ETo), *i.e.* 'P – Eto', accumulated over periods of one or more months. This approach makes it possible to characterize so-called "climate change-type" droughts, in which the increase in ETo exacerbates the water deficit even without a significant decrease in precipitation.

SPEI can be used to determine the onset, duration, and magnitude of drought conditions relative to normal conditions in various ecosystems. It shows anomalies (deviations from the long-term average) in water constraint at a given location and for a given accumulation period. The 'P – ETo' values are fitted to a probability distribution and then normalized, ensuring spatial and temporal comparability and facilitating interpretation[3].

SPEI applied to viticulture (SPEIv)

In order to adapt the *Standardized Precipitation-Evapotranspiration Index* to viticulture (SPEIv), it is important to take into account effective precipitation (Peff) and maximum crop evapotranspiration (ETc), which depends on the vine transpiration capacity (total transpiring leaf area and stomatal regulation). SPEIv is therefore determined from the difference between 'Peff – ETc'.

In our study, Peff corresponds to daily precipitation greater than or equal to 5 mm, but not exceeding 100 mm. Above this threshold, we hypothesize that the additional water should not be accounted for (losses due to deep drainage or runoff). These values were determined primarily from measurements taken by capacitive probes (using sensors at various depths) and observations of the root profile (soil pits). However, the accounting for effective rainfall can be refined by taking into account the amount of readily evaporable water, soil moisture status, and the temporal distribution of precipitation (since if there are several consecutive days with 5 mm of rain each, this threshold is likely too high).

ETc is determined daily by ETo weighted by a crop coefficient (Kc): 'ETc = Kc × ETo'. Kc reflects the crop development. Here, it is standardized according to the criteria proposed by Tonietto and Carbonneau (2004)[4] for their multi-criteria climatic classification system and is equal to 0.1 in April, 0.3 in May, and 0.5 from June to September during the vine growing season. It is nevertheless possible to adjust the criteria for determining Kc to more accurately reflect local conditions. To do so, calibration tests must be conducted to validate crop evapotranspiration.[5]

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SPEIv in the Mediterranean context

When applied to grapevine, SPEIv can be calculated using different time steps, such as a two-month accumulation period (SPEIv-2) to monitor vegetative growth and grape ripening, or a six-month period (SPEIv-6) for the overall characterization of a vintage. Peff and ETc values are then summed, and the difference D is calculated for each accumulation period over a minimum duration of 30 years.

Figure 2 shows the results of SPEIv-2 and SPEIv-6 in Perpignan, Roussillon, France, calculated over the 1996–2025 period. SPEIv-2 was determined over four periods to characterize water conditions prior to budbreak (February–March), flowering (April–May), veraison (June–July), and harvest (August–September). The index highlights anomalies in water availability relative to the crop water requirements four phases of vegetative and reproductive development. SPEIv-6 was determined for two periods: vegetative dormancy (October–March) and vegetative growth (April–September). The index allows for an objective quantification of the level of drought and, for example, shows no anomalies on either time scale during the 2025 vintage.



FIGURE 2. SPEIv-2 and SPEIv-6 indices in Perpignan, France (Météo France: 1996–2025). Class thresholds correspond to percentiles of the normal distribution. The green class, ranging from –1 to 1, encompasses approximately 68 % of events.

Conclusion

SPEIv is a relevant climate indicator because it captures abnormal periods of water stress and can help develop or refine climate change adaptation strategies. These water stresses disrupt or inhibit vine function and primarily affect yields, vineyard sustainability, and farm profitability in the short, medium, and long term. The index has limitations related to water transfer and retention in the soil; however, when combined with monitoring of the soil–root profile–plant–climatic demand continuum, it provides a better understanding of the interactions between soil water availability[6], plant response (depending on exposed leaf area, as well as the quality and quantity of production), and climate. Adopting and using this index requires initial training in the method, as with most decision-support tools.■

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Source: Sourced from the research article: "Grapevine, Berry and Soil Indicators to Manage Minimal Irrigation Strategy in Semi-Arid Conditions: Example of Grenache Noir (Vitis vinifera L.)" (Vitis, 2025).

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