

Article

Impact of Climate Change on Crop Yields: Insights from the Abruzzo Region, Central Italy

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Abstract: Climate change poses a major sustainability challenge, with potential far-reaching economic and social impacts, including fluctuations in agricultural yields and subsequent volatility in the availability and prices of essential food resources. In this study, we analyze the changes in climatic variables and agricultural yields for main crops cultivated in the Abruzzo Region (Central Italy), as well as their reciprocal correlation pattern in the time range, 1952–2014. Central Italy exhibits a well-developed agricultural sector and is characterized by a Mediterranean climate; given its proximity to the semi-arid and arid North African climate zone, such a region may be particularly vulnerable to climate change impacts. The analysis reveals an increase in drought intensity and persistence, starting from the 1980s, with a shift towards more temperate conditions in winter months and a transition to a warmer and more arid climate during the summer season. Moreover, the study identifies an overall increase in the correlation magnitude between crop yield fluctuations and climatic variables in the period 1983–2014 compared to that during the previous thirty-year time range. This finding can be interpreted as a change in the resilience (or increased vulnerability) of the agricultural production system to climate change. This work can be thus considered as an interesting case study in the Mediterranean region, offering valuable insights for constructing probabilistic models of fluctuations in agricultural production possibly induced by climate change.

Keywords: climate change; crop yield; agriculture; climatic trend; drought; correlation analysis



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1. Introduction

While remaining in a context characterized by great natural variability, the comparison between current variations and historical data reveals that our planet is experiencing a new phase of climate change compared to that of the pre-industrial era [1]. These effects raise concerns not only from an environmental point of view, but also from economic and social perspectives. Indeed, changes in climatic behavior can lead to fluctuations in agricultural yields, resulting in volatile consumer prices and a potential scarcity of even basic food resources for the population [2]. Consequently, the fight against climate change has become an urgent challenge requiring a collective response from all economic sectors and all levels of civil and political society. In the coming years, the world will need sufficient food resources to feed an ever-increasing population. However, at the same time, climate change is significantly impacting the basic resources for agriculture, compromising its traditional functions and demanding a fundamental reassessment of its development strategies and practices, with a strong emphasis on sustainability.

In this context, studying the local climate assumes a particular importance, especially for optimal management in various production sectors, such as agriculture. A thorough

understanding of the climatic features of a region remains a crucial element for profitable agricultural planning activities. Moreover, knowledge of the climate plays a fundamental role in assessing the productive potential, making it a valuable tool for institutional bodies involved in territorial planning.

There is a growing body of scientific literature on climatic trend analyses at different spatial and time scales. While there is a general agreement on global warming (with some variations owing to local features and the analyzed time frames), more heterogeneous patterns have been observed for precipitation, which are closely associated with atmospheric circulation variability [3].

The Mediterranean region, including Italy, adheres to these patterns and stands as an area that is particularly susceptible to current and future climate changes due to its transitional position between the tropical and temperate climates, along with its complex orography [4–9]. At a more local scale, comprehensive reviews of temperature and precipitation trends in Italian regions can be found in Scorzini and Leopardi [8] and Caporali et al. [9]. Focusing on Central Italy, and specifically on the Abruzzo Region, Scorzini and Leopardi [8] and Curci et al. [10] showed a general decrease in precipitation over the last century, but with a weak positive trend in all seasons during the last 30–40 years. Moreover, they reported significant increases in both the mean and extreme temperatures, with the most substantial warming occurring in summer, which has been particularly accentuated in recent decades. This finding has also been highlighted by Aruffo and Di Carlo [11], who observed a remarkable rise in the mean temperatures, estimating an approximate 20-fold increase from ~ 0.3 °C/century from the period 1924–1979 to ~ 6.0 °C/century in 1980–2015.

The simultaneous effects of severe warming and reduced rainfall have led to the frequent occurrence of droughts in Europe, posing a significant threat to the agricultural sector [12]. Several indices, including the Standardized Precipitation Index (SPI [13]), the Standardized Precipitation Evapotranspiration Index (SPEI [14]), the Palmer Drought Severity Index (PDSI [15]), the Soil moisture deficit index (SMDI [16]), and others, have been devised to assess drought occurrences and their attributes. Among these, SPI and SPEI are two of the most frequently used indices for drought monitoring [17], and various studies have recently analyzed possible correlations of these indices with crop yield anomalies in different regions of the world [18–29].

While certain previous works have examined the impact of climate on specific agricultural activities in the Abruzzo Region [30–32], in the present study, we conduct a correlation analysis of climatic variables and crop yields at the provincial level, with the objective of identifying potential causes of variations in agricultural yields attributable to climate change within the studied region. This may provide a framework of knowledge which might be preparatory to planning appropriate agro-climatic adaptation measures.

2. The Study Area

2.1. Main Geographic and Climatic Features

The Abruzzo Region (extending over an area of about 11,000 km²) is located in Central Italy (Figure 1) and is characterized by the Mediterranean climate. The geomorphological features of the region appear rather articulated, as a consequence of its paleoclimatic background [33] and of tectonic activities that reached their peak in the Neogene and are still ongoing [34,35]. These have conferred to the inner areas an arrangement characterized by alternating carbonate mountain ranges and NW–SE-oriented valleys, with mountains covering more than 70% of the regional area [36]. The provinces of Chieti, Pescara, and Teramo encompass both coastal and inland areas, featuring mountainous districts as well [37]. The province of L’Aquila, being the largest and farthest inland in the region, exhibits more intricate geomorphological and climatic characteristics compared to those of the others [38].

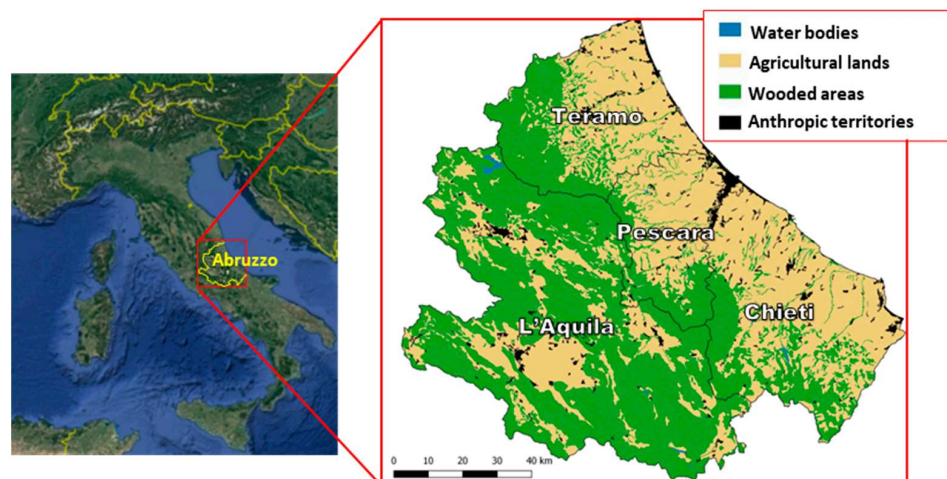


Figure 1. The study area with the identification of the four provinces and mainland-use types.

The regional climate is influenced by multiple factors, including latitude, altitude, the alignment of the outermost Apennines, which act as a barrier against western winds, and the tempering effect of the Adriatic Sea. In detail, two distinct climatic zones can be distinguished [8]:

- The internal belt (mountainous) characterized by a complex orography and exhibiting extensive high-altitude areas, such as mountains, basins, and valleys. This zone experiences various microclimates, with a prevailing semi-continental climate, featuring hot summers and cold winters;
- The eastern belt (hilly and coastal) characterized by a more uniform and typically Mediterranean climate, with hot summers and mild winters.

2.2. Agricultural Activity in the Abruzzo Region

The Abruzzo Region exhibits a well-developed agri-food sector with a normalized positive import–export balance above the national average [39]. The exports, primarily comprising cereals and derivatives, oils and processed fruit, and wine and wine grapes, are directed to Germany, the USA, and France.

The overall landscape of Abruzzo is characterized by the presence of wooded territories, with agricultural cultivation predominantly concentrated along the coastal areas and inland plains (Figure 1).

Spatially, over 2/3 of the regional water bodies and wooded areas are concentrated in the province of L'Aquila, while around 1/3 of the regional agricultural area is included in the province of Chieti [39], which accounts for about 3/4 of the regional grape production.

Production data from ISTAT (Italian National Institute of Statistics) [40,41] demonstrate significant changes in Abruzzo's agriculture over time (Figure 2A,B), with an increase in the number of cultivated species, a reduction in cultivated areas per single crop, and a remarkable overall increase in the agricultural yield. Particularly noteworthy is the more than doubled grape and olive production rates between 1952 and 2018; although, this was achieved through a significant reduction in their cultivation area. Data relating to the use of agricultural machinery and fuel use (oil, diesel, and petrol) provide an approximate measure of the growing trend of investments and mechanization in Abruzzo's agriculture in recent decades (Figure 2C,D). Data on fertilizer usage (nitrogen, phosphate, potassium, and organic and organic-mineral fertilizers; Figure 2E) also indicate an improvement in the agricultural techniques; their use increased until the late 1980s, followed by a gradual reduction in favor of more sustainable practices [39]. The irrigation system in Abruzzo is well developed and continuously undergoing technological, regulatory, and management improvements [36].

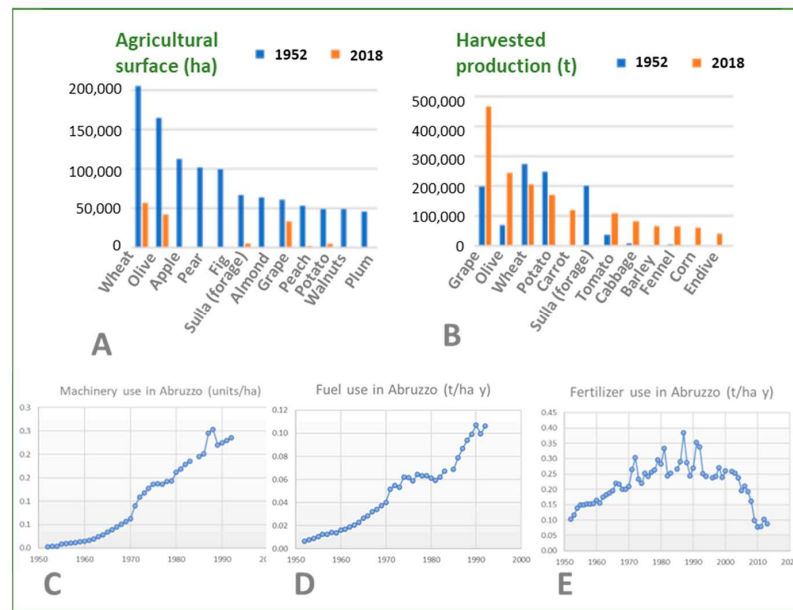


Figure 2. Comparison between 1952 and 2018 scenarios in Abruzzo in terms of cultivated area (A) and harvested production (B) per crop type. Time series of: machinery (C), fuel (D), and fertilizers (E) used in the agricultural system of Abruzzo.

3. Data and Methods

3.1. Climatic Data

The climatic analysis carried out in this study was based on monthly thermo-pluviometric data provided by the official publications of both Italian Hydrographic Service and Regional Hydrographic Service of Abruzzo and Campania Regions [8,10,42–44]. The selection of meteorological stations for analysis within the Abruzzo Region was guided by the sites' representativeness for an agro-climatic analysis. Priority was given to the stations situated within significant agricultural areas and below 800 m above sea level, thus minimizing the potential bias of high-altitude stations. This approach ensured the inclusion of a total of 35 rainfall and 17 thermometric stations that are uniformly distributed over the territory. These criteria facilitated the acquisition of comprehensive time series data spanning from 1952 to 2014.

For each station, the mean annual temperature, mean annual maximum and minimum temperatures, annual cumulated precipitation, as well as drought indices were calculated based on available monthly data.

Concerning the drought indices, we selected the Standard Precipitation Index (SPI) and the Standard Precipitation Evapotranspiration Index (SPEI), which are two of the most utilized indices for meteorology and drought assessments [17]. Both include information about the intensity, duration, and onset of a dry or a rainy period. Moreover, they are rather easy and quick to calculate compared to many other drought indices.

SPI [13] is a statistical indicator which compares the recorded precipitation P in each period of t months (where $t = 1, 3, 6, 12, \text{ or } 24$, months) to the aggregate long-term (e.g., over thirty years) precipitation distribution (P_{avg}, σ) for the same time range, as follows:

$$SPI = \frac{P - P_{Avg}}{\sigma} \quad (1)$$

SPI calculation involves fitting a probability density function, typically the gamma distribution, to the frequency distribution of precipitation totals for the chosen accumulation period. Through an equiprobability transformation, the estimated cumulative probability is then converted into a standard normal deviate, which provides the SPI value.

Similarly, the *SPEI* [14] represents the standardized effective rain value:

$$SPEI = \frac{D - D_{Avg}}{\sigma} \quad (2)$$

where D denotes the effective rain over the considered time span, which is the difference between cumulative monthly precipitation P and the cumulative monthly evapotranspiration ETP , as defined by Thornthwaite [45]. Since this method for evapotranspiration calculation is not particularly suitable in situations characterized by marked diurnal temperature fluctuations [46], which occur during the summer season in the province of L'Aquila, the *SPEI* index was assessed only for the other three provinces.

According to the World Meteorological Organization (WMO) classification [17], extreme drought and humidity are indicated by *SPI* (or *SPEI*) values below -2.0 and above 2.0 , respectively. Compared to *SPI*, the *SPEI* offers the crucial advantage of accounting for the impact of evapotranspiration on drought severity within the context of global warming; indeed, high temperatures drive high evapotranspiration rates, significantly influencing soil–atmosphere interactions and, consequently, surface runoff formation, infiltration, and groundwater recharge mechanisms.

Depending on the duration of the considered time range t , the *SPI/SPEI* provides useful information to evaluate the potential impacts of meteorological droughts:

- The short-term *SPI/SPEI* (1 to 3 months) indicates immediate impacts on soil moisture, snow cover and flow rate in small streams;
- The medium-term *SPI/SPEI* (3 to 6 months) assesses reductions in river flows and the crop production yield;
- The long-term *SPI/SPEI* (6 to 12 months) reveals changes in reservoir capacities and river flows;
- The very long-term *SPI/SPEI* (over 12 months) assesses the reduced recharge of reservoirs and large water basins and the availability of water in aquifers.

To assess the impact of droughts in the agricultural sector, we examined the following specific cases for monthly (*SPI1* and *SPEI1*), quarterly (*SPI3* and *SPEI3*), and semi-annual (*SPI6* and *SPEI6*) *SPI* and *SPEI* values in the months from March to December.

In addition to individual station data, time series aggregated at the provincial scale were also generated to be consistent with the available agricultural data.

3.2. Trend Analysis

A non-parametric Mann–Kendall test [47,48] was utilized to detect significant linear trends in the time series of the mentioned computed variables. The trend magnitude was quantified using the Theil–Sen approach [49], and the statistical significance of the trends was assessed at the 10% significance level. Trend analyses were carried out for both individual stations and provincially aggregated series.

The Mann–Kendall test was applied to the complete time series covering the period 1952–2014, as well as to two sub-periods, 1952–1982 and 1983–2014. The decision to divide the reference period into two halves was influenced by the findings from previous studies suggesting a change point in the late 1970s or early 1980s in the Abruzzo Region [8,50], which is in line with the tendencies at the global scale [51,52].

3.3. Climatic Classifications

Monthly climatic data at the provincial level were also employed to create Péguy climographs [53], which report the different mean monthly temperatures ($^{\circ}\text{C}$) and precipitation (mm) values on x and y axes, respectively. Twelve points, each corresponding to a month, are united to form a polygon encompassing an area that provides information on the climatic features of a region. A polygonal area predominantly aligned with the y -axis denotes a region marked by distinct variations in the total monthly rainfall, as opposed to

an elongated polygon parallel to the x-axis, indicating a climate characterized by substantial annual temperature fluctuations.

According to Pèguy [53], a triangular reference polygon with the following coordinates (0 °C; 0 mm), (23.4 °C; 40 mm), and (15 °C; 200 mm) divides the cartesian space into four climatic zones, as follows: temperate climate (within the area of the triangle), cold, arid, and warm (outside the triangle, starting from the top left of the graph, counterclockwise).

The provincial climographs for Abruzzo were assessed for the two considered sub-periods (1952–1982 and 1983–2014) to determine whether the change in climatic features also had an impact on the overall climatic classification of the area.

3.4. Agricultural Data

Agricultural data for Abruzzo were retrieved from ISTAT (Italian National Institute of Statistics) [40,41], which provides the annual time series information at the provincial scale of the harvested area and total production for each crop type; the crop yield can be then defined as the ratio between the two mentioned quantities.

The following procedure was adopted to identify the main crops in the Abruzzo Region for the subsequent correlation analysis with climatic data:

- (1) The harvested area and production (Figure 2) values for all crops in Abruzzo were sorted in descending order for the years 1952 and 2018;
- (2) Only crops that covered at least 75% of the total harvested area and accounted for at least the same percentage of the total production were considered;
- (3) Crops that were present in only one of the two reference years were excluded to avoid those crops that were cultivated only in the past or that have been introduced recently.

Following these criteria, three crops emerged as significant representatives of Abruzzo's agricultural production: wheat, grape, and olive.

Before performing any correlation analysis between the yields and drought indices, the corresponding time series were detrended. Indeed, beyond the climate, several other external factors can have an impact on the variations in crop yields, such as the introduction of new management practices and technologies, the use of fertilizers, more productive varieties, and more efficient irrigation techniques that all concur to an increase in crop yields over time. In order to remove the effect of these factors, and thus isolate the variation in the yield resulting from the climate, a yield reduction and standardization technique was used following the procedure described in Potopova et al. [18]. The standardized yield residuals (SYRS) were calculated for each crop and province, as follows:

$$SYRS = \frac{YDT - \mu}{\sigma} \quad (3)$$

where YDT denotes the yield residuals; μ and σ the yield residual average and standard deviation, respectively. Yield residuals were calculated as the difference between the observed crop yields (Y_0) and those estimated using a linear regression model (Y):

$$YDT = Y_0 - Y \quad (4)$$

The utilized linear regression models were based on the observed crop yield data (Y_0) relating to the two studied thirty-year time ranges, 1952–1982 and 1983–2014.

3.5. Correlation Analysis between Crop Yields and Drought Indices

Correlation analysis was aimed at establishing how and to what extent climate change has affected agricultural productivity in the Abruzzo Region over the analyzed time intervals. Such an analysis has been carried out by relating SPI and $SPEI$ drought indices—viewed as summarizing the climate indicators—with detrended agricultural yields ($SYRS$) over the two considered thirty-year time ranges, and then comparing results. The analysis, at the provincial level, involved the main crops cultivated in the region (wheat, olive, and grape), and it was performed at the monthly, quarterly, and semi-annual time scales,

spanning from March to December. The effect of droughts on the crop yields was evaluated through the Pearson's correlation coefficient, R .

It is noteworthy to emphasize here that the primary objective of this analysis was to detect alterations in the correlation coefficients across the two examined time intervals, rather than solely assessing their magnitudes. These variations can be, therefore, interpreted as a measure of the sensitivity of the agricultural production system to climate change.

4. Results

4.1. Climatic Analysis

The following sections present the results of the analysis of the climatic variables in the Abruzzo Region by highlighting the different scenarios between the two considered sub-periods, 1952–1982 and 1983–2014.

4.1.1. Precipitation Trend Analysis

Figure 3 illustrates a static map of the mean annual cumulative precipitation over Abruzzo for the period 1952–2014, along with indicators denoting detected trend direction and significance (significant trends at the 10% level) at each individual station. The figure also presents trend magnitudes for the provincial time series during the two examined sub-periods.

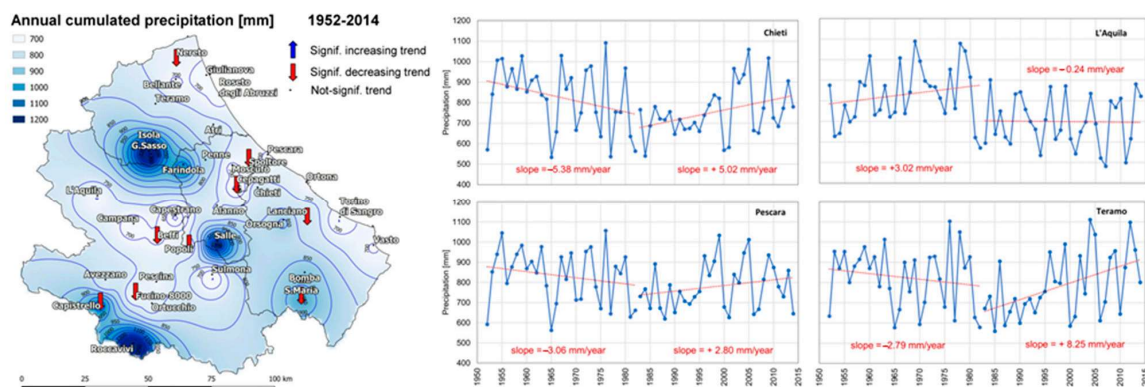


Figure 3. Map of the mean annual cumulative precipitation over 1952–2014, with indication of trend sign and significance (significant trends at 10% level) at the individual stations (left). Trend magnitude for the provincial time series of cumulated precipitation over the two sub-periods 1952–1982 and 1983–2014 (right). Red lines denote trendlines over thirty-year time ranges.

The overall trend indicates general rainfall reduction over the analyzed time range (1952–2014), which is more marked in the provinces of Chieti and L'Aquila (Figure 3). Nevertheless, different patterns can be identified for the two sub-periods, with a notable decrease in the first thirty years in all provinces, with exception of L'Aquila, exhibiting a positive trend over 1952–1982, but with a strong precipitation reduction concentrated in the early 1980s. The provinces of Chieti and Teramo show, instead, a moderate increasing trend over the last thirty-year time range.

4.1.2. Temperature Trend Analysis

The results of the trend analysis applied to the annual mean temperature for the total reference period and for the two sub-windows are summarized in Figure 4, which clearly denote widespread warming tendencies in the region. However, in this general area, two different patterns can be distinguished between 1952–1982 and 1983–2014, with the first case indicating a reduction in the mean temperature in large part of the region, as opposed to a more recent sudden warming trend that occurred in the second 30-year time span. This registered the highest rates of change, as also confirmed by the provincial time series for the mean annual maximum and minimum temperatures (Figure 5).

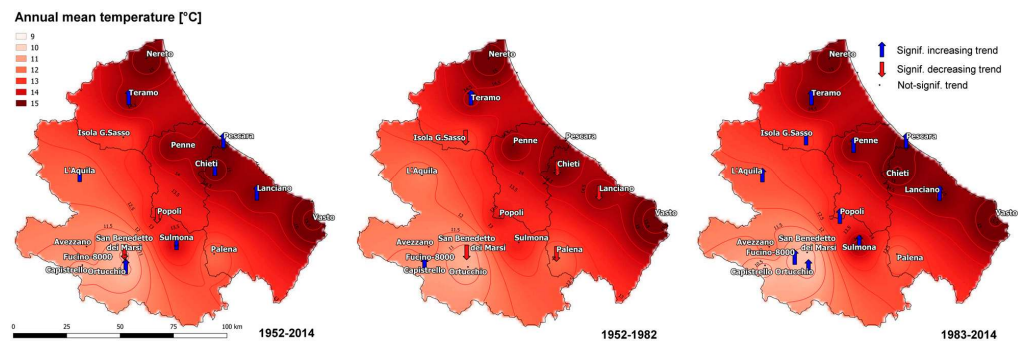


Figure 4. Maps of the annual mean temperature with indication of trend sign and significance (significant trends at 10% level) for different time ranges: 1952–2014 (left), 1952–1982 (center), and 1983–2014 (right).

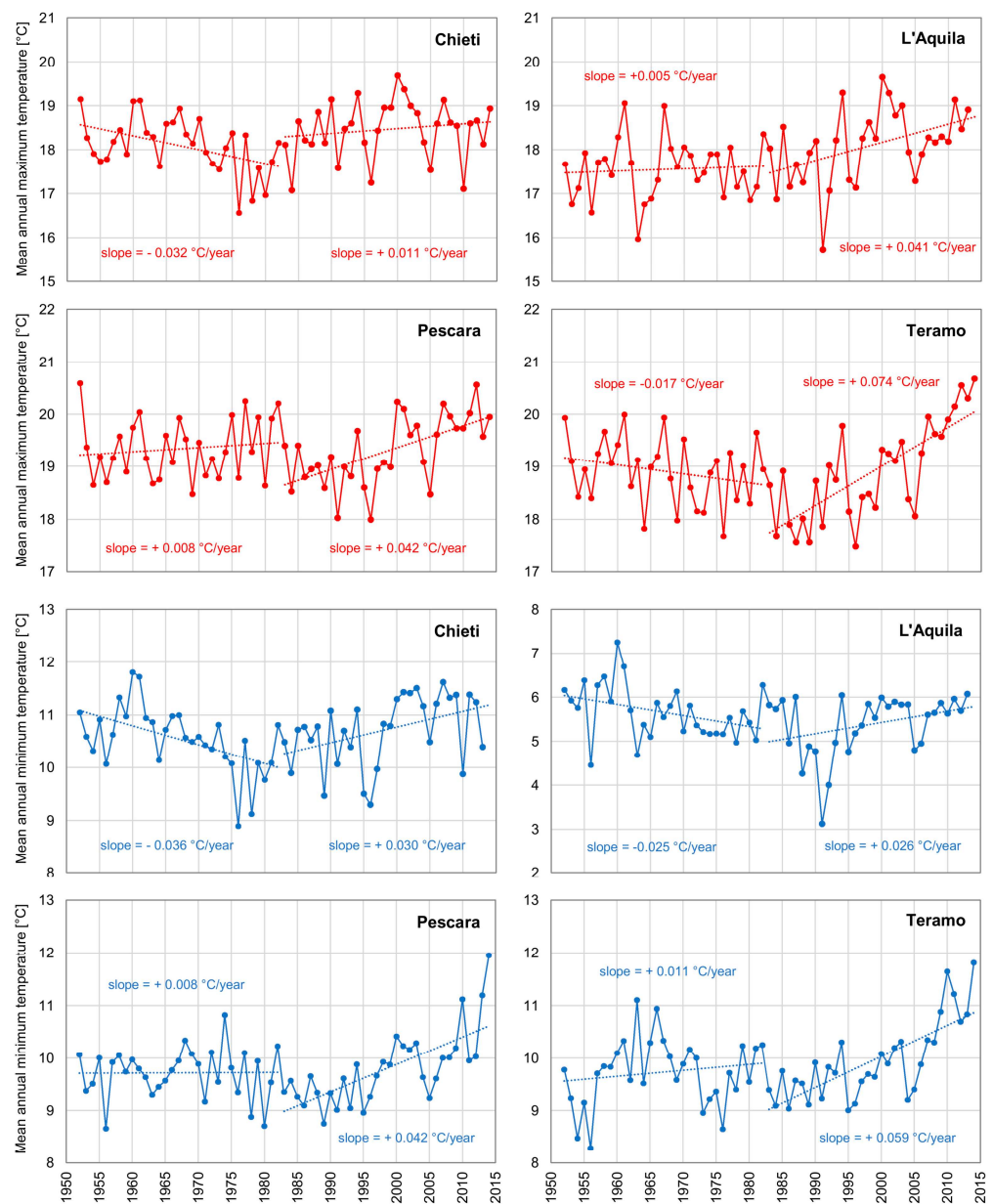


Figure 5. Provincial time series of mean annual maximum (red) and minimum (blue) temperatures, with indication of trend magnitude. Dotted lines denote trendlines over thirty-year time ranges.

4.1.3. Climatic Classification

In order to better highlight the changes that occurred during the analyzed periods, climographs for the four provinces were plotted for the two reference thirty-year periods, 1952–1982 and 1983–2014 (Figure 6).

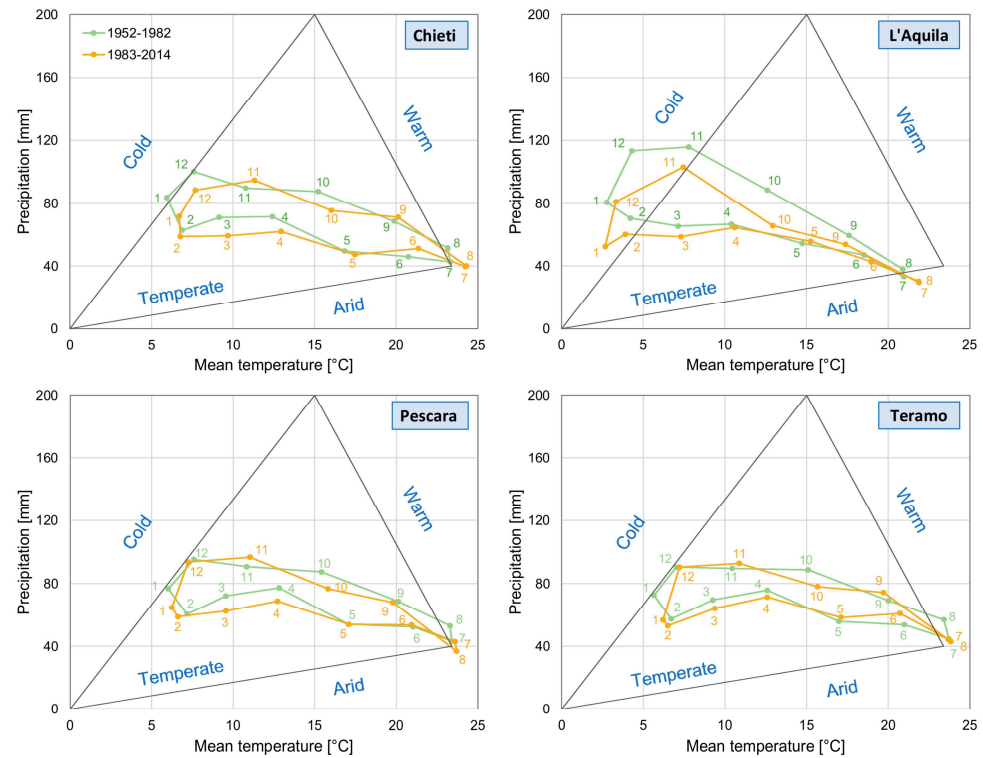


Figure 6. Péguy climographs for the four studied provinces, in the time ranges 1952–1982 (green) and 1983–2014 (orange). Numbers 1 to 12 refer to the months of the year (from January to December).

Figure 6 shows that the polygonal areas corresponding to all the provinces exhibit a substantial elongation along the temperature axis that is indicative of climatic conditions characterized by pronounced annual temperature ranges, while in L'Aquila, a marked gradient in precipitation is also evident. Most vertices of these polygons, representing average monthly climatic conditions, predominantly reside within the climatic triangle, except for certain extreme instances, notably the winter (December and January) and the summer months (July and August). With reference to the two sub-periods, it is possible to observe:

- In the province of Chieti, in July and August, it transitioned from having temperate or borderline conditions to arid during the second three decades. This shift resulted from elevated average temperatures coupled with decreased rainfall;
- In the province of L'Aquila, in July and August, it shifted to arid conditions in the later three decades due to increased temperatures. Conversely, in February and November, with stable average temperatures, the region experienced diminished precipitation, leading to a more temperate climate. A substantial reduction in rainfall exceeding 30 mm is evident in January and December during the latter period.
- In the province of Pescara, the overall climograph remained relatively consistent, except for July and August, during which it shifted from warm to dry due to decreased precipitation.
- In the province of Teramo, July and August persisted as warm months, while January transitioned to the temperate category due to increased temperatures and reduced rainfall.

4.1.4. Drought Indices

To provide a visual representation of the evolving drought conditions within the region, Figure 7 displays the detected trends' signs and significance at individual stations (on the left) alongside provincial-scale time series (on the right) for some selected *SPI* indices. Analogous provincial time series for *SPEIs* are reported in Figure 8.

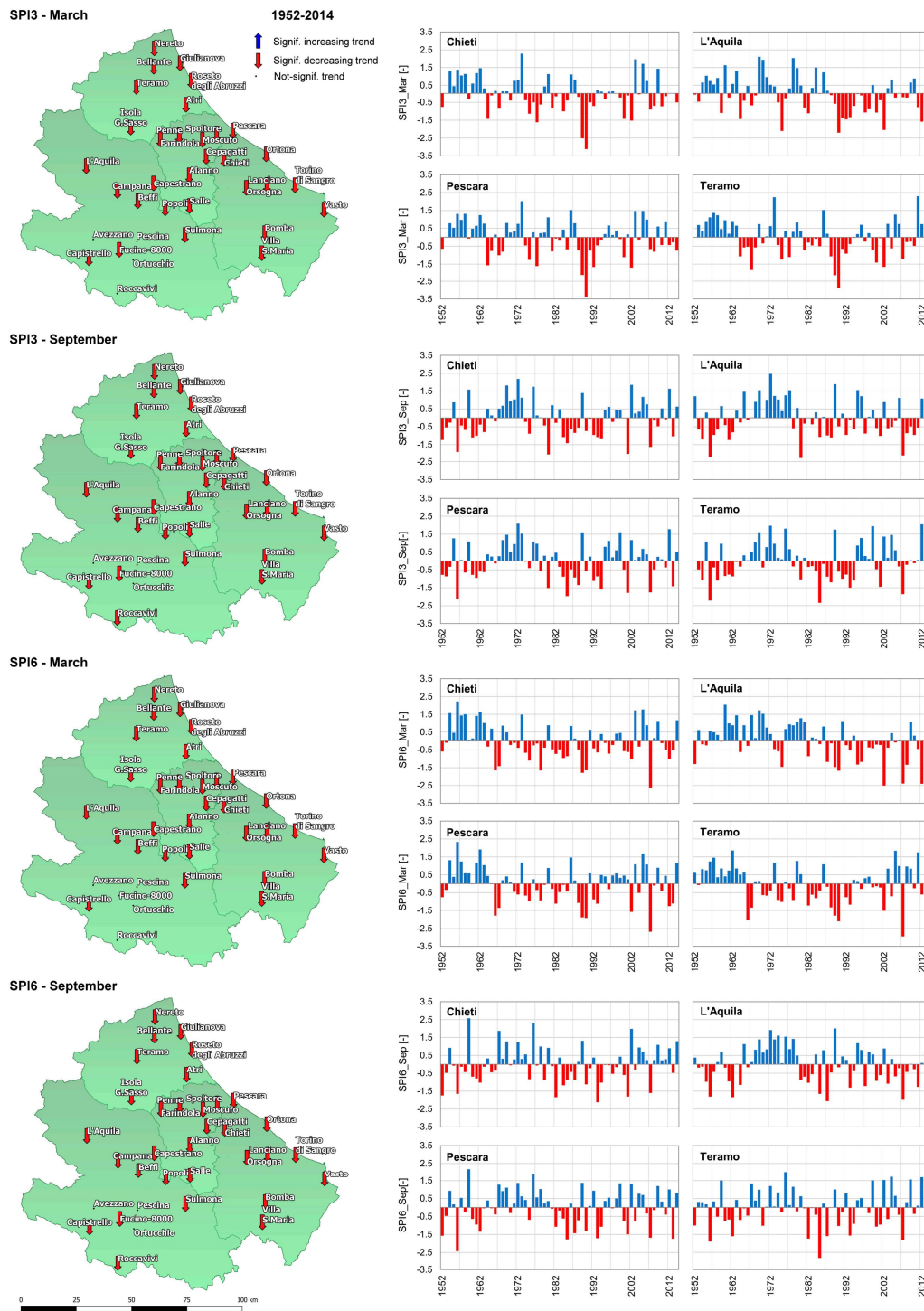


Figure 7. Trend sign and significance (significant trends at 10% level) at the individual stations for quarterly and semi-annual *SPIs* for March and September over 1952–2014 (left) and corresponding provincial time series (right). Blue and red colors in time series denote values above or below the average, respectively.

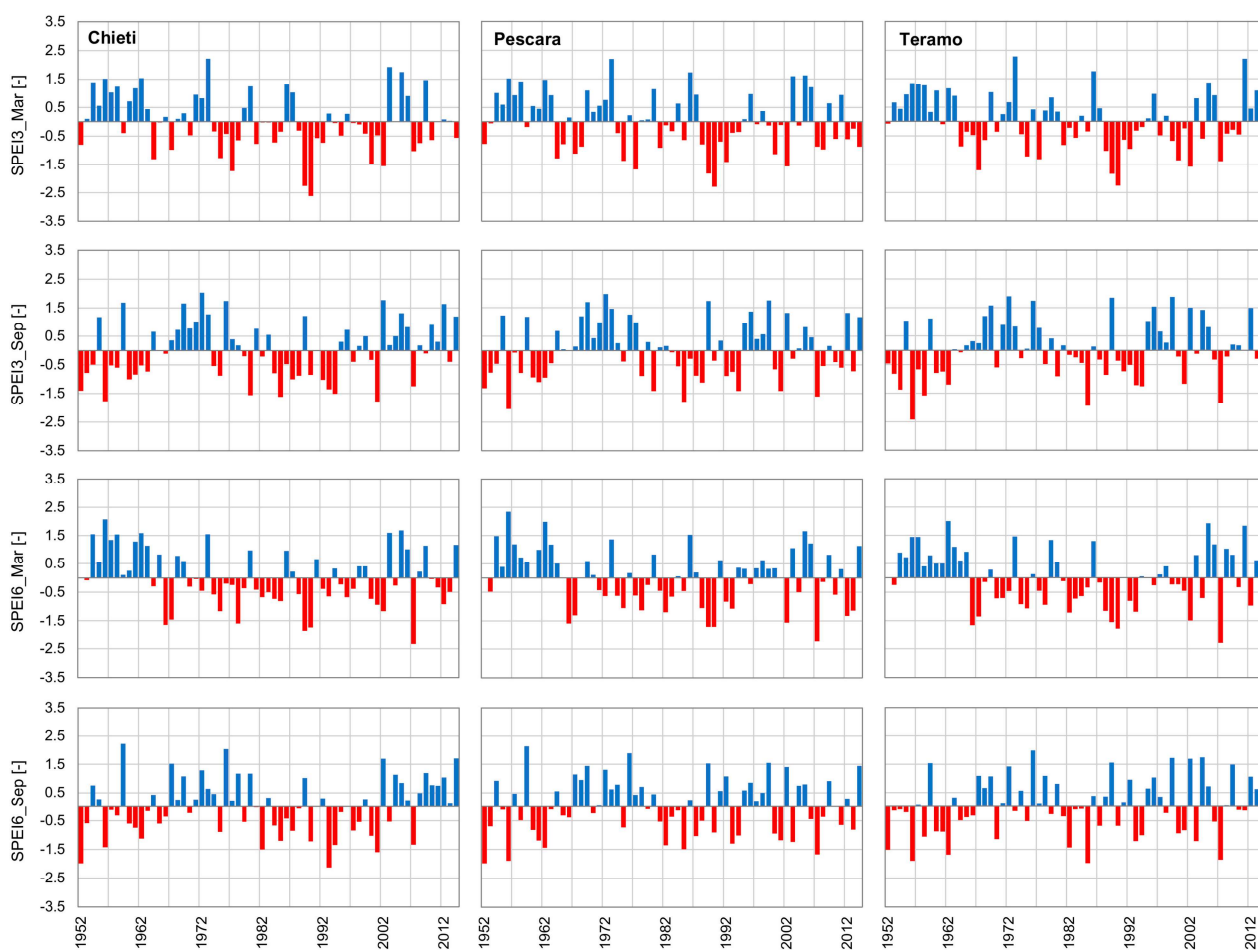


Figure 8. Provincial time series for quarterly and semi-annual SPEIs for March and September in 1952–2014. Blue and red colors denote values above or below the average, respectively.

The Mann–Kendall test applied to all the examined *SPIs* illustrate an overall decreasing trend over 1952–2014, which is indicative of an intensifying drought scenario. On the other hand, distinct trends emerge when the two thirty-year periods, 1952–1982 and 1983–2014, are isolated, with the former exhibiting a decreasing trend, while the latter showcases a slight increase that remains associated with prevalent drought conditions. These data reveal severe drought episodes, particularly in the coastal area in the late 1950s and in the 1980s, which are separated by years characterized by severe humidity.

The declining trend in the shown *SPI* indices suggests diminishing rainfall during the respective seasons. A comparative analysis of the two periods accentuates a general tendency toward amplified drought occurrences during the summer months, which is further corroborated by the time series of the examined *SPEI* indices (Figure 7).

4.2. Agricultural Yield Data

Figure 9 illustrates the 1952–2014 provincial time series for wheat, olive, and grape yields in Abruzzo, with an indication of the average values calculated for the two considered time spans.

Regarding wheat, a consistent upward trend in yields has been sustained across all the examined provinces, manifesting at a nearly constant rate of approximately 0.04–0.05 t/ha per year. Similarly, grape cultivation has also demonstrated a steady and comparable growth pattern ranging from 0.04 t/ha per year in L’Aquila to 0.20 t/ha per year in Teramo.

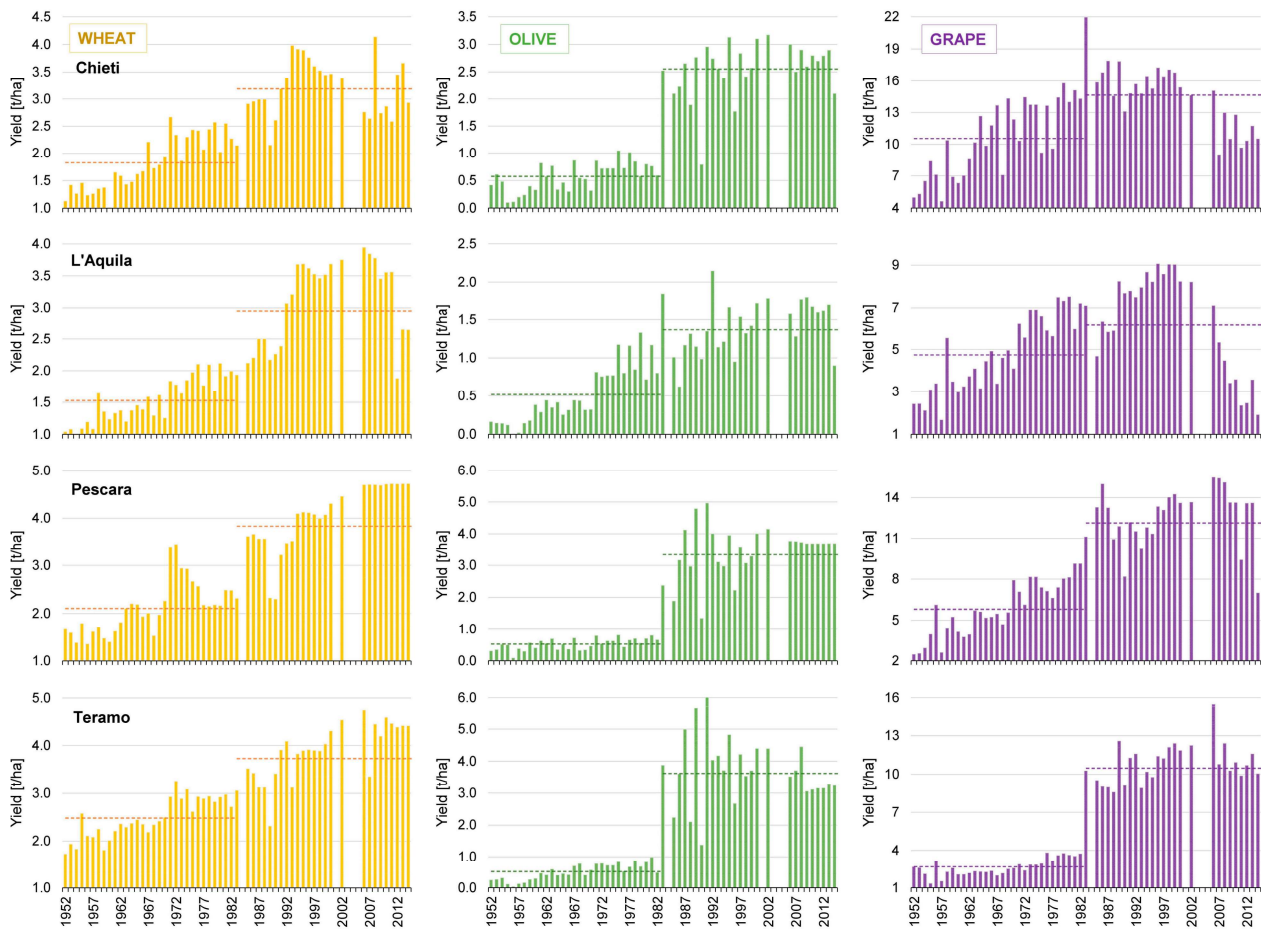


Figure 9. Provincial time-series of wheat, olive, and grape yields, with indication of average values calculated over 1952–1982 and 1983–2014.

Conversely, for olive cultivation, an abrupt enhancement in yields is evident in the year 1983, encompassing the entire region; this improvement translates to over a five-fold increase in yields between the two examined sub-periods.

4.3. Correlation Analysis of Crop Yields and Drought Indices

The results of the correlation analysis are shown in Figure 10, which allows us to evaluate the impact of climatic conditions on the yields of wheat, olive, and grape, as well as the variation between the two considered thirty-year periods. For each table, the same legend is used, which takes into account:

- Correlation sign: positive correlations are represented by blue (dark or light) filled squares, while negative correlations are denoted by red squares.
- Correlation significance: the statistical significance of the correlation was checked using the two-tailed Student's *t*-test at the 10% and 1% significance levels, which are associated with the threshold correlation values (see the legend in Figure 10).

For wheat, in Abruzzo, sowing takes place in October–November, with harvesting taking place in June–July. Therefore, the most relevant indices for this crop are: December *SPI/SPEI3*, which is related to seed germination and the following stages; March *SPI/SPEI3* and *SPI/SPEI6* affect the tillering stage, and June *SPI/SPEI3* affects the picking, earing, flowering, and ripening stages. For this crop, with the exception of the province of L'Aquila, in several cases, there is a generalized increase in the correlation values and significance (red/dark blue cells) in the most recent period.

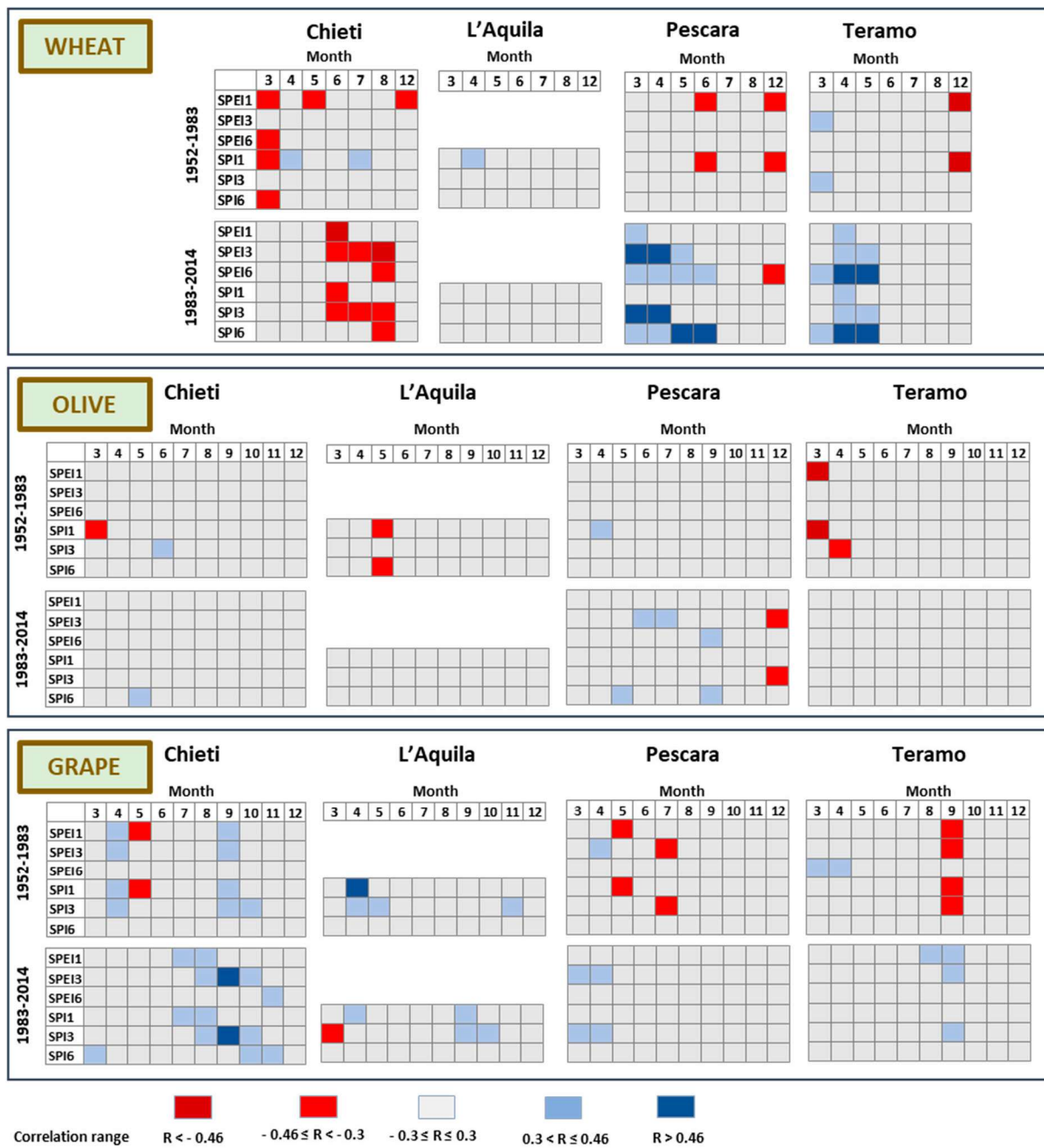


Figure 10. Identified correlation coefficients between detrended crop yield (*SYRS*) and relevant *SPI* and *SPEI* indices for wheat, olive, and grape for the four studied provinces and for the time ranges 1952–1982 and 1983–2014.

In the province of Chieti, in 1983–2014, stronger negative correlations of the yield with the summer-related *SPEIs* appear to be more numerous, reaching higher *R* values for July–August *SPI/SPEI3* up to -0.46 . Pescara and Teramo show a generalized increase in the positive correlation between the yield and winter/spring-related indices, with maximum values of *R* detected for March–April *SPI/SPEI3* (~ 0.5 – 0.6) and April–May *SPI/SPEI6* (0.49 – 0.53).

The olive yield exhibits an overall low correlation with the considered *SPIs* and *SPEIs*, which also does not show significant changes over time. Given the inherent cyclical nature of this particular crop’s production, it seems reasonable to observe low correlation values

with the examined indices; indeed, production fluctuations in excess or deficiency may be often associated with non-climatic factors rather than variations in the *SPI/SPEI*.

In the province of Chieti, in the second 30-year period, it is possible to observe a notable increase in the correlation between the grape crop yields and indices linked to the summer and autumn seasons, with *R* values reaching 0.46 and 0.50 for September *SPI3* and *SPEI3*, respectively. In the other three studied provinces, the correlation values do not show significant variation over time. However, considering that Chieti contributes a substantially larger share of grape production compared to the combined output of the other three provinces, the yield data from Chieti holds significant influence in representing the overall regional production.

5. Discussion

This study provides a comprehensive overview of the climate in the Abruzzo Region and its changes spanning from 1952 to 2014. According to the Péguy climographs, Abruzzo experiences a temperate–temperate humid climate, with average temperatures of 15 °C along the coast and 10 °C inland. Notably, marked changes in precipitation and temperatures have been observed since the early 1980s. The province of L'Aquila witnessed the most significant reduction in winter rainfall, reaching −20%. Over the last 20–30 years, droughts have increased in intensity and persistence compared to those of the past, affecting not only the coastal area, but also certain inland zones. *SPI* and *SPEI* indices both indicate a worsening in drought severity, which is mainly associated with rising average temperatures and declining winter rainfall.

Before delving into the results of correlation analysis between the observed climatic variations and crop yields, it is important to highlight some specific characteristics of the three considered crops.

Firstly, wheat in Abruzzo is a rainfed (i.e., not irrigated) crop, and, therefore, it is expected to be particularly sensitive to water stresses, including both extreme drought and waterlogging at specific phenological phases [54]. Olive exhibit an alternating production pattern, with biennial fluctuations in fruit production favoring intrinsic interannual variability [55,56]. As a result, such a behavior is expected to reduce the correlation with the considered climatic indices, as production fluctuations may be often associated with non-climatic factors. Furthermore, olive and grape cultivated in Italian regions are associated with valuable products, such as oil and wine, which are characterized by high prices [57]. Therefore, the investment made in the cultivation phase to mitigate any unfavorable external effect is likely influenced by market-related processes. In other words, the resilience of the production system for such crops can be significantly affected by economic factors rather than solely climate-related causes.

Finally, to ensure clarity in data interpretation, it is important to underline that positive or negative correlation values should not be mistaken as indicating a favorable or unfavorable impact of the climate on agricultural yields; instead, a positive correlation suggests that droughts are a limiting factor for the yield, while a negative one indicates that an excessively humid climate may have a limiting effect. It should be recalled here that the main purpose of this work is the identification of variations in the correlation between agricultural production and climatic indices over time. In other words, it is not merely essential to observe a significant positive or negative correlation for a specific index; rather, what matters is whether there is a change in the occurrence of statistically significant correlation values between the two reference periods, 1952–1982 and 1983–2014 (i.e., in practical terms, more colored cells (in red or blue) appear in the second period than those in the first). This change should be interpreted as an indication of the resilience of the agricultural production system to climatic variations (i.e., more sensitivity to the climate). It is useful to underline that, although the considered agricultural production system shows a progressive yield growth, an increase in the frequency and/or amplitude of production oscillations highlights, on the one hand, an inability of the system itself to maintain a good performance even in unfavorable climatic conditions. On the other hand, yield fluctuations

(sometimes even positive ones) always represent a potential disturbing element of related market equilibria.

The overall analysis of Figure 10 reveals a more notable increase in significant statistical correlations between the agricultural yields and various climatic indices during 1983–2014 in comparison to that during the previous thirty-year period. In particular, for wheat, except in the province of L’Aquila, there is a generalized increase in the correlation values, as well as in significance (dark red/blue cells) in several cases. On the other hand, as expected due to its intrinsic interannual yield variability, the olive situation remains relatively unchanged over time. In the case of grape, there is an increase in the correlation values only for the province of Chieti, which is, however, the largest producer of vines among the four analyzed provinces.

Given the relatively small sample size of the two 30-year sub-data sets, it should be noted that correlation values, taken individually, can offer only limited insights, particularly when introducing additional climatic variables. For example, consider the values in Table 1, which displays the percentage of years in which the quarterly SPEI of March and the minimum daily temperature averaged over the winter season, were above or below the mean values for the province of Pescara in the two considered periods (indicated in the table with a sign “+” and “–”, respectively). For instance, the value 16, which is associated with two negative signs in the period 1952–1982, indicates that in 16% of cases, the winter climate was dry cold (i.e., with an SPEI and minimum temperature below the mean values). Comparing data between the two studied time ranges reveals distinct distributions of moderately and very cold years for the same SPEI value (e.g., below average).

Table 1. Table of occurrences (as percentage) of years in which the quarterly SPEI of March and the minimum daily temperature averaged over the winter season were above or below the mean values for the province of Pescara. Plus and minus signs in the columns (lines) denote SPEI (minimum temperature) above and below the mean value, for the respective thirty-year time range.

		SPEI			
		1952–1982		1983–2014	
		+	–	+	–
Min. temp.	+	29	29	19	30
	–	26	16	22	30

This implies that correlation analysis with this SPEI may yield different correlation values for the two considered time intervals. Nevertheless, the complete picture illustrated in Figure 10 still offers significant information. By treating the significance associated with each correlation value as a binomial variable, with the events being the rejection/non-rejection of the null hypothesis, Figure 10 can be interpreted as an occurrence table comparing two data sets of 81 values each (considering only the SPEI (as the SPI provide similar results) and accounting for the stochastic dependence of many considered SPEI indices). Such an occurrence table points out that, overall, (i.e., considering all the analyzed provinces and crops), in the second thirty years (1983–2014), the agricultural yields were influenced by a higher number of climatic features and to a greater extent in several cases (i.e., where cells are in dark red or blue). In other words, in the second considered thirty-year period, there is a stronger correlation compared to that of the first between climatic fluctuations and oscillations in the yield of the studied crops.

It is also worth mentioning that the continuous improvement in agricultural techniques and technological progress have enhanced the agricultural productivity of the studied region by mitigating the effect of unfavorable climatic conditions. Additionally, agricultural strategies have evolved over time, driven by commercial demands. For instance, the olive tree harvesting now tends to take place earlier and earlier each year to meet the market preferences for bitter extra virgin olive oil. Furthermore, some modern farms are also currently equipped with irrigation systems for olive trees and protection against late frosts.

In the correlation analysis presented here, efforts were made to minimize the influence of these factors on agricultural yield using the yield residual detrending technique, achieving statistically significant results.

6. Perspective for Future Research

The analysis carried out in this study, although providing some basic elements on the assessment of the impact of evolving climate on crop production, does not consider some of the main variables that come into play within a complex dynamic system, which involves the natural productive system, on one side, and markets and main economic variables on the other.

Although these kinds of evaluations lie beyond the scope of this work, it is useful to draw some relevant considerations in this regard. Let us consider various possible interventions aimed at mitigating the unfavorable effects of climatic fluctuations on the agricultural yield (e.g., irrigation, protection against late frosts, etc.), which might be summarized in the economic variable “investments” (INV). Additionally, consider the different stakeholders involved in the agri-food system, including the producers, distributors, and final consumers (i.e., the user population), as well as the main involved economic variables, such as production and distribution costs and producer and consumer prices. In an ideal production system, whenever adverse climatic conditions occur (e.g., drought, frost, etc.), production can be maintained at the desired target level through increased investments (INV). According to this model, one would expect to detect a strong statistical correlation between fluctuations in climatic indices and investments, while a very low correlation (or even zero-correlation) would be expected between the climatic indices and agricultural yield. This is one of the main limitations of statistical analysis, which does not take appropriate economic variables into consideration. Moreover, even in an optimistic scenario of a perfectly resilient production system, an increase in investments (INV) would have repercussions on other variables, from production cost to consumer prices, potentially hindering food accessibility for the population.

However, the reality is more complex than this ideal scenario is, as the effectiveness of interventions in mitigating climatic effects may not always be guaranteed. Additionally, the investment size in the agricultural production phase depends on interactions with local and/or international markets and economic forecasting logics. Hence, a promising avenue for future research in this field would involve carrying out an analysis similar to the one illustrated here, but also incorporating various economic variables. This expanded approach would shed further light on how economic forces influence agricultural practices and how they interact with climatic variations to impact the crop yields. Such a comprehensive analysis would provide valuable insights for policymakers and stakeholders seeking to enhance agricultural resilience and sustainability in the face of changing climate conditions and market dynamics.

Another potential issue with the current analysis is related to the scale of observation. Likely, data on agricultural yields at the provincial scale might be too generalized to expect a significant correlation with the drought indices. Furthermore, the climatic condition itself is not uniform on a provincial scale. For instance, the province of L'Aquila, with an extension of over 5000 km² and complex geomorphological and climatic settings, may experience extreme negative conditions in some areas and favorable conditions in others. In such context, averaging the climatic and production variables might involve a relevant loss of information. Future studies may provide improved criteria for the scale setting of this kind of statistical analysis.

7. Conclusions

This study illustrated a detailed statistical analysis of the relationships between the climatic conditions and yields over 1952–2014 for the main crops grown in the Abruzzo Region, i.e., wheat, olive, and grape. The results of the analysis carried out at the provincial scale and for two sub-periods 1952–1982 and 1983–2014 can be summarized as follows:

- Over the two considered time periods, the region's climatic classification has undergone a transformation, with a shift towards more temperate conditions in the winter months and a transition to warmer and more arid climate during the summer season;
- SPI and SPEI drought indices point out an increase in drought intensity and persistence, starting from the 1980s;
- In contrast to 1952–1982, the period 1983–2014 exhibited a distinct rise in the correlation magnitude between the crop yields and climatic drought indices. Despite the progressive improvements in the agricultural production system, this shift should be interpreted as a sign of its increasing sensitivity to climate stresses.

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References

1. IPCC. Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis*; Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK, 2021.
2. Abbass, K.; Qasim, M.Z.; Song, H.; Murshed, M.; Mahmood, H.; Younis, I. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ. Sci. Pollut. Res.* **2022**, *29*, 42539–42559. [[CrossRef](#)] [[PubMed](#)]
3. Nguyen, P.; Thorstensen, A.; Sorooshian, S.; Hsu, K.; Ashouri, H.; Tran, H.; Braithwaite, D.; AghaKouchak, A. Global Precipitation Trends across Spatial Scales Using Satellite Observations. *Bull. Am. Meteorol. Soc.* **2018**, *99*, 689–697. [[CrossRef](#)]
4. Giorgi, F.; Lionello, P. Climate change projections for the Mediterranean region. *Glob. Planet. Change* **2008**, *63*, 90–104. [[CrossRef](#)]
5. Michaelides, S.; Karacostas, T.; Sánchez, J.L.; Retalis, A.; Pytharoulis, I.; Homar, V.; Romero, R.; Zanis, P.; Giannakopoulos, C.; Bühl, J.; et al. Reviews and perspectives of high impact atmospheric processes in the Mediterranean. *Atmos. Res.* **2018**, *208*, 4–44. [[CrossRef](#)]
6. Tuel, A.; Eltahir, E.A. Why is the Mediterranean a climate change hot spot? *J. Clim.* **2020**, *33*, 5829–5843. [[CrossRef](#)]
7. Fioravanti, G.; Piervitali, E.; Desiato, F. A new homogenized daily data set for temperature variability assessment in Italy. *Int. J. Clim.* **2019**, *39*, 5635–5654. [[CrossRef](#)]
8. Scorzini, A.R.; Leopardi, M. Precipitation and temperature trends over central Italy (Abruzzo Region): 1951–2012. *Theor. Appl. Clim.* **2018**, *135*, 959–977. [[CrossRef](#)]
9. Caporali, E.; Lompi, M.; Pacetti, T.; Chiarello, V.; Fatichi, S. A review of studies on observed precipitation trends in Italy. *Int. J. Climatol.* **2021**, *41*, E1–E25. [[CrossRef](#)]
10. Curci, G.; Guijarro, J.A.; Di Antonio, L.; Di Bacco, M.; Di Lena, B.; Scorzini, A.R. Building a local climate reference dataset: Application to the Abruzzo region (Central Italy), 1930–2019. *Int. J. Clim.* **2021**, *41*, 4414–4436. [[CrossRef](#)]
11. Aruffo, E.; Di Carlo, P. Homogenization of instrumental time series of air temperature in Central Italy (1930–2015). *Clim. Res.* **2019**, *77*, 193–204. [[CrossRef](#)]
12. Spinoni, J.; Vogt, J.V.; Naumann, G.; Barbosa, P.; Dosio, A. Will drought events become more frequent and severe in Europe? *Int. J. Climatol.* **2018**, *38*, 1718–1736. [[CrossRef](#)]

13. McKee, T.B.; Doesken, N.J.; Kleist, J. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA, 17–22 January 1993; Volume 17, No. 22. pp. 179–183.
14. Vicente-Serrano, S.M.; Beguería, S.; López-Moreno, J.I. A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. *J. Clim.* **2010**, *23*, 1696–1718. [[CrossRef](#)]
15. Palmer, W.C. *Meteorological Drought*; US Department of Commerce, Weather Bureau: Washington, DC, USA, 1965; Volume 30.
16. Narasimhan, B.; Srinivasan, R. Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring. *Agric. For. Meteorol.* **2005**, *133*, 69–88. [[CrossRef](#)]
17. World Meteorological Organization (WMO); Global Water Partnership (GWP). *Handbook of Drought Indicators and Indices*; Svoboda, M., Fuchs, B.A., Eds.; Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2; World Meteorological Organization (WMO) and Global Water Partnership (GWP): Geneva, Switzerland, 2016; ISBN 978-92-63-11173-9.
18. Potopová, V.; Boroneanț, C.; Boincean, B.; Soukup, J. Impact of agricultural drought on main crop yields in the Republic of Moldova. *Int. J. Clim.* **2016**, *36*, 2063–2082. [[CrossRef](#)]
19. Bezdán, J.; Bezdán, A.; Blagojević, B.; Mesaroš, M.; Pejić, B.; Vranešević, M.; Pavić, D.; Nikolić-Đorić, E. SPEI-Based Approach to Agricultural Drought Monitoring in Vojvodina Region. *Water* **2019**, *11*, 1481. [[CrossRef](#)]
20. Gunst, L.; Rego, F.M.C.C.; Dias, S.M.A.; Bifulco, C.; Stagge, J.H.; Rocha, M.S.; Van Lanen, H.A.J. *Links between Meteorological Drought Indices and Yields (1979–2009) of the Main European Crops*; Technical Report No. 36; DROUGHT-R&SPI Project: Wageningen, The Netherlands, 2015.
21. Peña-Gallardo, M.; Vicente-Serrano, S.M.; Domínguez-Castro, F.; Beguería, S. The impact of drought on the productivity of two rainfed crops in Spain. *Nat. Hazards Earth Syst. Sci.* **2019**, *19*, 1215–1234. [[CrossRef](#)]
22. Peña-Gallardo, M.; Vicente-Serrano, S.M.; Domínguez-Castro, F.; Quiring, S.; Svoboda, M.; Beguería, S.; Hannaford, J. Effectiveness of drought indices in identifying impacts on major crops across the USA. *Clim. Res.* **2018**, *75*, 221–240. [[CrossRef](#)]
23. Blauhut, V.; Gudmundsson, L.; Stahl, K. Towards pan-European drought risk maps: Quantifying the link between drought indices and reported drought impacts. *Environ. Res. Lett.* **2015**, *10*, 014008. [[CrossRef](#)]
24. Bachmair, S.; Tanguy, M.; Hannaford, J.; Stahl, K. How well do meteorological indicators represent agricultural and forest drought across Europe? *Environ. Res. Lett.* **2018**, *13*, 034042. [[CrossRef](#)]
25. Labudová, L.; Labuda, M.; Takáč, J. Comparison of SPI and SPEI applicability for drought impact assessment on crop production in the Danubian Lowland and the East Slovakian Lowland. *Theor. Appl. Climatol.* **2017**, *128*, 491–506. [[CrossRef](#)]
26. Martinez, C.J.; Baigorria, G.A.; Jones, J.W. Use of climate indices to predict corn yields in southeast USA. *Int. J. Clim.* **2009**, *29*, 1680–1691. [[CrossRef](#)]
27. Parsons, D.J.; Rey, D.; Tanguy, M.; Holman, I.P. Regional variations in the link between drought indices and reported agricultural impacts of drought. *Agric. Syst.* **2019**, *173*, 119–129. [[CrossRef](#)]
28. Chen, T.; Xia, G.; Liu, T.; Chen, W.; Chi, D. Assessment of Drought Impact on Main Cereal Crops Using a Standardized Precipitation Evapotranspiration Index in Liaoning Province, China. *Sustainability* **2016**, *8*, 1069. [[CrossRef](#)]
29. Tian, L.; Yuan, S.; Quiring, S.M. Evaluation of six indices for monitoring agricultural drought in the south-central United States. *Agric. For. Meteorol.* **2018**, *249*, 107–119. [[CrossRef](#)]
30. Di Lena, B.; Farinelli, D.; Palliotti, A.; Poni, S.; DeJong, T.M.; Tombesi, S. Impact of climate change on the possible expansion of almond cultivation area pole-ward: A case study of Abruzzo, Italy. *J. Hortic. Sci. Biotechnol.* **2018**, *93*, 209–215. [[CrossRef](#)]
31. Di Lena, B.; Curci, G.; Vergni, L.; Farinelli, D. Climatic Suitability of Different Areas in Abruzzo, Central Italy, for the Cultivation of Hazelnut. *Horticulturae* **2022**, *8*, 580. [[CrossRef](#)]
32. Di Carlo, P.; Aruffo, E.; Brune, W.H. Precipitation intensity under a warming climate is threatening some Italian premium wines. *Sci. Total Environ.* **2019**, *685*, 508–513. [[CrossRef](#)]
33. Giraudi, C.; Magny, M.; Zanchetta, G. Drysdale the Holocene climatic evolution of Mediterranean Italy: A review of the continental geological data. *Holocene* **2011**, *21*, 105–115. [[CrossRef](#)]
34. Cosentino, D.; Cipollari, P.; Marsili, P.; Scrocca, D. Geology of the central Apennines: A regional review. In *The Geology of Italy: Tectonics and Life along Plate Margins*; Beltrando, M., Peccerillo, A., Mattei, M., Conticelli, S., Doglioni, C., Eds.; Journal of the Virtual Explorer, Electronic Edition; 2010; Volume 36, p. 11. ISSN 1441-8142. [[CrossRef](#)]
35. Cosentino, D.; Asti, R.; Nocentini, M.; Gliozzi, E.; Kotsakis, T.; Mattei, M.; Esu, D.; Spadi, M.; Tallini, M.; Cifelli, F.; et al. New insights into the onset and evolution of the central Apennine extensional intermontane basins based on the tectonically active L'Aquila Basin (central Italy). *Bull. Geol. Soc. Am.* **2017**, *129*, 1314–1336. [[CrossRef](#)]
36. Zucaro, R.; Pontrandolfi, A. *Rapporto Sullo Stato dell'Irrigazione in Abruzzo*; Istituto Nazionale di Economia Agraria INEA: Rome, Italy, 2008. Available online: <https://sigrian.crea.gov.it/wp-content/uploads/2020/11/2008-Rapporto-sullo-stato-dellirrigazione-in-Abruzzo.pdf> (accessed on 15 August 2023).
37. Piacentini, T.; Buccolini, M.; Miccadei, E. The Terminillo, Gran Sasso and Majella Mountains: The 'Old Guardians' of the Tyrrhenian and Adriatic Seas. In *Landscapes and Landforms of Italy. World Geomorphological Landscapes*; Soldati, M., Marchetti, M., Eds.; Springer: Cham, Switzerland, 2017.
38. Santo, A.; Ascione, A.; Di Crescenzo, G.; Miccadei, E.; Piacentini, T.; Valente, E. Tectonic-geomorphological map of the middle Aterno river valley (Abruzzo, Central Italy). *J. Maps* **2014**, *10*, 365–378. [[CrossRef](#)]

39. Regione Abruzzo, 2014. Sviluppo Rurale in Abruzzo nel 2014–2020. Available online: https://rica.crea.gov.it/APP/PSR_2014_2020/download/04_AnalisiDiContesto.pdf (accessed on 10 July 2023).
40. ISTAT, Biblioteca Digitale-Annuario di Statistica Agraria. Available online: <https://ebiblio.istat.it/SebinaOpac/resource/annuario-di-statistica-agraria/IST0010796> (accessed on 15 August 2023).
41. ISTAT, Dati-Agricoltura-Coltivazioni-Superfici e Produzione. Available online: <http://dati.istat.it> (accessed on 15 August 2023).
42. Annali Idrologici della Regione Abruzzo, Ufficio Idrografico e Mareografico—Pescara. Available online: <https://www.regione.abruzzo.it/content/annali-idrologici?page=2> (accessed on 15 August 2023).
43. Annali Idrologici della Regione Campania, Centro Funzionale Multirischi della Protezione Civile Regione Campania, Annali Idrologici e Altre Pubblicazioni del Compartimento di Napoli del S.I.M.N. Available online: <http://centrofunzionale.regione.campania.it/#/pages/documenti/annali> (accessed on 15 August 2023).
44. Scorzini, A.R.; Di Bacco, M.; Leopardi, M. Recent trends in daily temperature extremes over the central Adriatic region of Italy in a Mediterranean climatic context. *Int. J. Clim.* **2018**, *38*, e741–e757. [[CrossRef](#)]
45. Thornthwaite, C.W. An Approach toward a Rational Classification of Climate. *Geogr. Rev.* **1948**, *38*, 55–94. [[CrossRef](#)]
46. Beguería, S.; Vicente-Serrano, S.M.; Reig, F.; Latorre, B. Standardized precipitation evapotranspiration index (SPEI) revisited: Parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. *Int. J. Climatol.* **2014**, *34*, 3001–3023. [[CrossRef](#)]
47. Mann, H.B. Non-Parametric Test against Trend. *Econometrica* **1945**, *13*, 245–259. [[CrossRef](#)]
48. Kendall, M.G. *Rank Correlation Methods*, 4th ed.; Charles Griffin: London, UK, 1975.
49. Sen, P.K. On a Further Robustness Property of the Test and Estimator Based on Wilcoxon’s Signed Rank Statistic. *Ann. Math. Stat.* **1968**, *39*, 282–285. [[CrossRef](#)]
50. Di Lena, B.; Antenucci, F.; Mariani, L. Space and time evolution of the Abruzzo precipitation. *Ital. J. Agrometeorol.* **2012**, *1*, 5–20.
51. Klein Tank, A.M.G.; Wijngaard, J.B.; Können, G.P.; Böhm, R.; Demarée, G.; Gocheva, A.; Mileta, M.; Pashiardis, S.; Hejkrlik, L.; Kern-Hansen, C.; et al. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *Int. J. Climatol.* **2002**, *22*, 1441–1453. [[CrossRef](#)]
52. Jones, P.D.; Moberg, A. Hemispheric and Large-Scale Surface Air Temperature Variations: An Extensive Revision and an Update to 2001. *J. Clim.* **2003**, *16*, 206–223. [[CrossRef](#)]
53. Péguy, C.P. *Précis de Climatologie*, 2nd ed.; Masson: Paris, France, 1970; 468p.
54. Ding, J.; Huang, Z.; Zhu, M.; Li, C.; Zhu, X.; Guo, W. Does cyclic water stress damage wheat yield more than a single stress? *PLoS ONE* **2018**, *13*, e0195535. [[CrossRef](#)]
55. Orlandi, F.; Rojo, J.; Picornell, A.; Oteros, J.; Pérez-Badia, R.; Fornaciari, M. Impact of Climate Change on Olive Crop Production in Italy. *Atmosphere* **2020**, *11*, 595. [[CrossRef](#)]
56. Rojo, J.; Salido, P.; Pérez-Badia, R. Flower and pollen production in the ‘Cornicabra’ olive (*Olea europaea* L.) cultivar and the influence of environmental factors. *Trees* **2015**, *29*, 1235–1245. [[CrossRef](#)]
57. Teslić, N.; Zinzani, G.; Parpinello, G.P.; Versari, A. Climate change trends, grape production, and potential alcohol concentration in wine from the “Romagna Sangiovese” appellation area (Italy). *Theor. Appl. Climatol.* **2018**, *131*, 793–803. [[CrossRef](#)]

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