Predicted Changes in Precipitation in the Mediterranean Basin Could Promote Olive Tree Health Throughout Italy

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Abstract

The predicted 30% precipitation decrease and 3°C temperature increase in the Mediterranean Basin may increase water stress on vegetation. The changing climate could negatively impact economic and environmental processes throughout Italy. This paper examines RapidEye satellite imagery and Meteoblue reanalysis data to test the hypothesis that olive grove vegetative health is positively impacted by an increase in rainfall yet negatively impacted by high intensity precipitation events throughout Italy. The correlation analyses between vegetation indices—Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI)—and varying precipitation thresholds for eleven olive orchards revealed that summer precipitation positively correlated with harvest season NDVI. A correlation analysis between precipitation intensity (PI) and VCI for each orchard showed that the impact of PI on NDVI varies based on the season, total annual rainfall of the region, and slope of the orchard.

Key Points:

1. Summer precipitation and harvest season NDVI are positively correlated
2. The impact of precipitation intensity varies based on season, slope, and sum precipitation
3. Olive tree health would likely increase as summer precipitation intensity increases

1 Introduction

The Mediterranean Basin is characterized by hot summer temperatures and low rainfall (Caloiero et al., 2011). Predicted weather changes in a warming regional climate would increase the water stress on vegetation (Viola et al., 2013). Decreasing precipitation coupled with an increase in evapotranspiration, evaporation of water from the earths surface coupled with plant transpiration, due to increasing temperature could lead to a 30% decrease in olive yield over the next 120 years (Viola et al., 2013). Olive trees, a staple economic and environmental product in the Mediterranean region, are vulnerable to these changes in climate. Olive growth in Italy is influential in national economic activity, but also minimizes erosion and desertification of this semi-arid region, and improves the carbon balance in the area (Viola et al., 2013). The predicted decrease in olive yield over the next 120 years could cause a 30% gross income loss for farmers in the area (Viola et al., 2013).

For the past two centuries, precipitation in the Mediterranean Basin has decreased (Brunetti et al., 2012). The negative trend is most pronounced in areas of high elevation (Caloiero et al., 2011). In the Calabria region of Italy, seasonal rainfall models show a negative trend in annual and winter rains, amplified in areas of high elevation, yet a positive trend for summer precipitation (Caloiero et al., 2011). Brunetti et al. (2012) found the same trend, a negative total precipitation and winter precipitation trend and a positive summer trend, in Spain. In the next 120 years, precipitation in the Mediterranean is predicted to decrease by roughly 30% and temperatures are predicted to rise 3°C (Viola et al., 2013). Studying the effect of water depletion on irrigated systems, Wahibi et al. (2005) found that a 50% decrease in water applied to the olive trees results in a 15% to 20% decrease in fruit yield on the effected trees.

In the Calabria region, the number of days with non-zero precipitation is decreasing, while the intensity of these events displays a positive trend with time (Caloiero et al., 2011). The more intense an event is, the more water reaches the ground in a shorter period of time. An increase in high intensity precipitation could lead to increased waterlogging, the saturation of the ground with water often from irrigation or precipitation, in olive orchards. Olive trees are classified as sensitive to hypoxia, lack of oxygen (Argues et al., 2004). The waterlogged soil slows down gas diffusion, leading to significant oxygen depletion and increases in carbon dioxide at the root site (Theo M. Elzenga & Hans van Veen, 2010). Hypoxia forces root cells to switch to aerobic respiration to create energy through glycolysis, the breaking down of sugar to create ATP, yet cells create 37% less ATP under oxygen deficient conditions (Theo M. Elzenga & Hans van Veen, 2010). The lack of energy halts root growth and new root formation. Waterlogging also leads to denitrification of the soil and, therefore, reduced plant nutrients. As a result of lack of oxygen, microbial respiration occurs with the intake of nitrogen and iron rather than oxygen (Theo M. Elzenga & Hans van Veen, 2010). Studies conducted on olive orchards using flood irrigation concluded that places of low elevation were affected by severe waterlogging in irrigated fields and 55% of the trees studied had died after 3.5 years (Argues et al., 2004).

2 Data and Methods

This research initially examined eight olive orchards throughout Italy: Ca Rainene in the north, La Selvotta in central Italy, Enotre, Olearia San Giorgio, and Tenute Librandi Pasquale in Calabria, and Agrestis, Feudo Disisa, and Baglio di Pianetto in Sicily. I then added three additional orchards, Frantoio Hermes, Frantoio di Cornoledo, and Frantoio de Carlo, for additional data (Figure 1). All weather data were obtained from MeteoBlue, a 35-year, hourly weather model simulation with a 30 km spatial resolution (https://www.meteoblue.com/). All imagery was acquired by the RapidEye satellites and accessed through Planet (https://www.planet.com/). RapidEye satellite sensors report five spectral bands, Blue (b1), Green (b2), Red (b3), Red Edge (b4), and Near Infra Red (b5), captured at 6.5 meter nominal ground resolution. To correct for background interference, I adjusted the individual multispectral images using Dark-Object Subtraction (DOS). The DOS correction identified the darkest pixel in each image by summing b1, b2, and b3 for each pixel and identifying the pixel with the lowest sum. For the darkest pixel, b1, b2, and b3 were set to 0. The same correction was performed on all subsequent pixels. NDVI is a red and near infrared band ratio, commonly used to identify vegetation, calculated from multispectral images. I used VCI (Vegetation Condition Index), a normalized form of NDVI, to measure vegetation health. VCI, which was used for cross regional comparisons as advocated by Kefi et al. (2016), was calculated with the following equation:

$$NDVI = (b5 - b3)/(b5 + b3)$$
$$VCI = 100 * (NDVI - NDVI_{\text{min}})/(NDVI_{\text{max}} - NDVI_{\text{min}})$$

A bare-ground adjustment further corrected for atmospheric interference. To make the bare-ground adjustment, I subtracted the NDVI of an urban center near each orchard, which should remain nearly zero over time, from the NDVI of each orchard for all images.

I calculated the average elevation and mean, maximum, and median slope of each orchard using topographic data. To calculate slope, I compared the elevation of each pixel with the elevation of the surrounding pixels and found the greatest elevation change. Slope was calculated in the direction of the greatest elevation change using the equation $\sqrt{(x^2 + y^2)}$, where (x, y) represents the location and elevation of any given point.

I calculated correlation coefficients for NDVI and VCI, averaged over July, August, and September, and sum precipitation, averaged over various time frames, over the past ten years. The time frames I examined were April-June, May-July, June-August, April-May, May-June, June-July, July-August, and the individual months of May, June, July, and August. After summing the precipitation, given by the hourly Meteoblue weather data, over each day for 34 years, I calculated precipitation intensity by dividing the sum monthly precipitation by the number of rainy days each month. Rain days are defined as any day receiving a non-zero sum of rain. I calculated correlation coefficients for the precipitation intensity in various months and the NDVI in the following months with various lags.

	Latitude [°]	Elevation [m]	Slope (avg.)	Slope (max.)	Slope (med.)	Precipitation Intensity [mm/day]	Annual Sum Precipitation [mm]
Agrestis	37.14	677	0.21	0.38	0.21	2.9	626
Baglio di Pianetto	37.98	537	0.31	0.58	0.31	3.6	651
Enotre	39.09	460	0.24	1.17	0.21	4.6	1178
Fuedo Disisa	37.95	368	0.17	0.60	0.16	4.2	522
Tenute Librandi Pasquale	39.59	345	0.28	1.14	0.25	4.5	307
Olearia San Giorgio	38.37	308	0.04	0.05	0.04	5.9	517
Frantoio Hermes	42.46	277	0.24	0.57	0.23	5.4	627
Ca'Rainene	45.61	227	0.33	1.07	0.32	6.6	869
Frantoio de Carlo	41.04	101	0.02	0.12	0.02	4.2	339
Frantoio di Cornoledo	45.23	76	0.22	0.71	0.21	4.4	727
La Selvotta	42.07	56	0.06	0.32	0.03	4.8	510

Figure 1: Latitude [°], avg. elevation, avg. slope ($\sqrt{(x^2+y^2)}$), max slope, med. slope, avg. precipitation intensity (PI) [mm/day], and avg. annual sum precipitation [mm] for each orchard researched. Listed in order of descending elevation.

3 Results

VCI, averaged over July-September, and the sum precipitaion of various months show significant positive correlation for Feudo Disisa, Tenute Librandi Pasquale, Olearia San Giorgio, Ca Rainene, and La Selvotta (Figure 2). Orchards with higher average precipitation intensity at a lower elevation (Figure 1), Ca Rainene and Olearia San Giorgio, showed significant positive trends in July and August, while orchards with precipitation intensity below 5 mm/day and mean elevation below 500 m (Figure 1), Feudo Disisa, Tenute Librandi Pasquale, and La Selvotta, showed significant positive correlation in the month of May. Two significant negative trends were discovered: the correlation of sum precipitation in April and April-May and July- September average VCI for Olearia San Giorgio (Figure 2), and the correlation of July-August sum precipitation with July-September

	Jul-Sept VCI [%] and April Precip. [mm]	Jul-Sept VCI [%] and May Precip. [mm]	Jul-Sept VCI [%] and June Precip. [mm]	Jul-Sept VCI [%] and July Precip. [mm]	Jul-Sept VCI [%] and August Precip. [mm]
Agrestis	0.189	0.202	0.205	0.558	0.263
Baglio di Pianetto	-0.018	-0.094	0.366	0.002	-0.527
Enotre	-0.448	-0.526	0.710	0.480	0.413
Feudo Disisa	-0.360	**0.881**	0.006	0.095	-0.655
Tenute Librandi Pasquale	0.020	**0.634**	0.174	0.136	0.055
Olearia San Giorgio	**-0.684**	0.083	0.582	-0.436	**0.777**
Ca Rainene	-0.086	0.024	0.463	**0.708**	0.185
La Selvotta	0.025	**0.762**	0.204	-0.069	-0.467

Figure 2: Correlation coefficients VCI with dark-object and bare-ground subtraction, averaged over July, August, and September, and varying sum precipitation time frames. Blue bolded correlation coefficients represent correlations for which the null hypothesis can be rejected. Black bolded correlation coefficients are reported with a 90% confidence interval based on p-values returned by the correlation analysis. No significant trends present for Agrestis or Baglio di Piannetto. Orchards are listed in order of decreasing elevation.

VCI for Feudo Disisa. Increasing elevation negatively correlates with average annual precipitation intensity (Figure 1).

Correlation analysis of average PI in February, a month with the highest precipitation intensity (Figure 3), and VCI averaged over March and April, for four orchards, showed varying trends. February PI and March-April VCI for Feudo Disisa showed a significant negative trend (Figure 4). Feudo Disisa is a flat orchard with moderate precipitation intensity and mid-range average elevation for this data set (Figure 1).

Correlation analysis of average PI in June, a month with the lowest precipitation intensity (Figure 3), and VCI averaged over July and August, for four orchards, showed solely positive trends. The null hypothesis can be rejected for the positive correlation of July-August VCI and average June precipitation intensity for Frantoio de Carlo (Figure 4). Frantoio de Carlo is a flat orchard with moderate precipitation intensity and low sum annual precipitation at a low elevation (Figure 1).

4 Discussion

This research examined three relationships: elevation and precipitation intensity, monthly sum precipitation and vegetation health [VCI], and average monthly precipitation intensity and vegetation health [VCI].

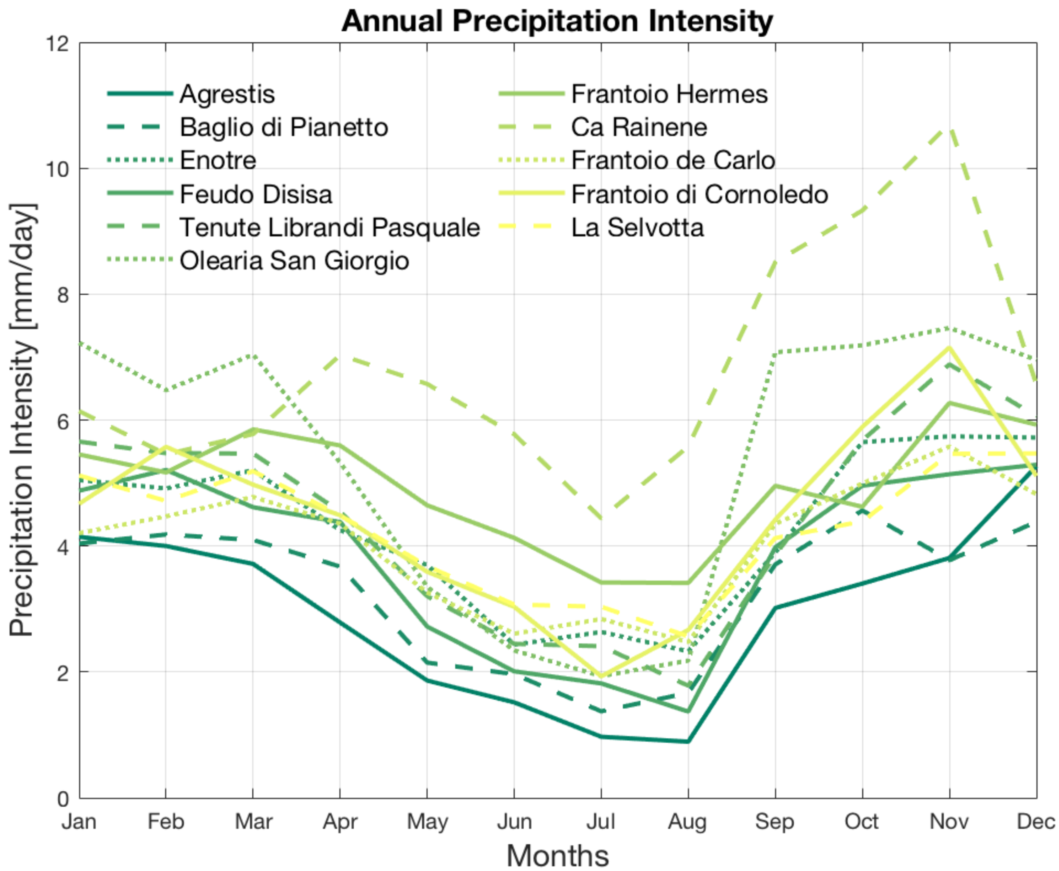

Figure 3: Monthly precipitation intensity for 11 orchards, averaged over 10 years of meteoBlue data. The orchards are plotted from dark green to yellow in order of decreasing average elevation (Figure 1). The darkest plot represents the orchard at the highest average elevation (Agrestis). Highest precipitation intensity occurs in the winter months for all the orchards. Lowest precipitation intensity occurs in the summer for all orchards.

4.1 Elevation and Precipitation Intensity

As elevation increases, precipitation intensity decreases (Figure 1). VCI, averaged over June, July, and August, showed no positive or negative trends with monthly sum precipitation for orchards at high elevations with low precipitation intensity. Precipitation intensity does not correlate with annual sum precipitation averaged over 10 years (Figure 1). The lack of correlation indicates that orchards with lower precipitation intensity that receive relatively mid-range annual precipitation, Agrestis and Baglio di Pianetto, receive varied rainfall throughout the year—a higher number of lower intensity events—rather than a smaller number of higher intensity events. The less intense rainfall, experienced by orchards at higher elevations, results in VCI that is not dependent upon rainfall from any one month, shown in Figure 2 by the lack of significant correlations for Agrestis and Baglio di Pianetto.Caloiero et al. (2011) observed a negative trend in precipitation that is amplified in areas of high elevation in Calabria, Italy. This could further decrease precipitation intensity in the future.

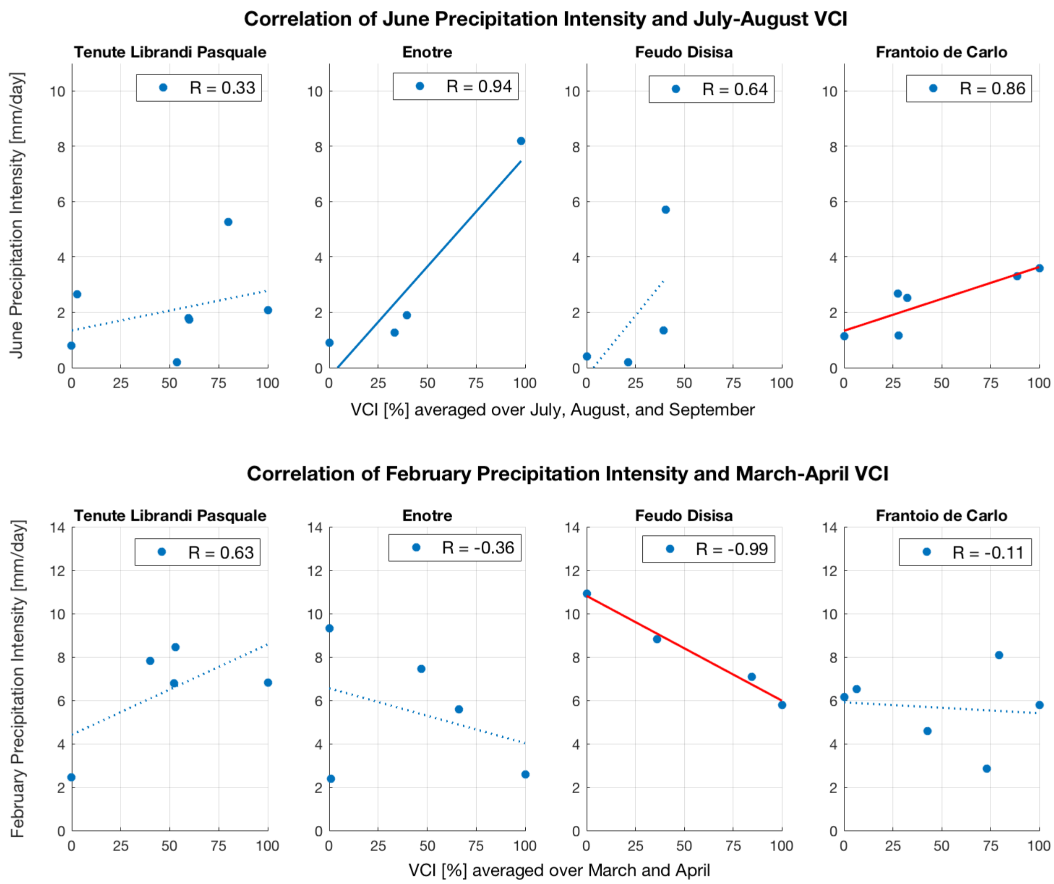

Figure 4: *TOP:* Correlation analysis for VCI [%], averaged over July and August, and average June precipitation intensity [mm/day], over the past ten years, for four orchards. R-values listed represent the correlation coefficients. *BOTTOM:* Correlation analysis for VCI [%], averaged over March and April, and average February precipitation intensity [mm/day], over the past ten years, for four orchards. R-values listed represent the correlation coefficients. Red trend lines represent correlations for which the null hypothesis can be rejected based on p-values returned by the correlation analysis: Frantoio de Carlo and Feudo Disisa. Blue solid trend lines represent correlations reported with a 90% confidence interval based on p-values returned by the correlation analysis: Enotre

4.2 Sum Precipitation and NDVI

For orchards with an elevation below 500 m, summer precipitation positively correlated with the olive vegetation health during the late summer/ harvest season (July, August, and September). Orchards at a lower elevation with higher precipitation intensity, Olearia San Giorgio and Ca Rainene, positively depended on late summer rains occurring in July or August. Olearia San Giorgio, a flat orchard (Figure 1), showed a positive trend with late summer rains but a significant negative trend with spring rains. Olive trees at Olearia San Giorgio, sensitive to waterlogging and hypoxia, respond negatively to earlier season rains, which are more intense (Figure 3). Feudo Disisa, Tenute Librandi Pasquale, and La Selvotta, all orchards with moderate precipitation intensity (Figure 1), positively correlate with late spring/early summer sum precipitation occurring in May. Fuedo Disisa and Tenute Librandi Pasquale are at mid-range elevations (Figure 1). La Selvotta is located at sea level and directly on the coast, which effects its climatology. Total summer precipitation in the Calabria region is increasing slightly, though the positive trend is overshadowed by decreasing precipitation in the winter creating an overall significant negative sum precipitation (Caloiero et al., 2011). Similar patterns were discovered in Spain (Brunetti et al., 2012).This trend could be beneficial for olive tree health in the Mediterranean Basin: if intense early spring and winter precipitation events decrease and summer rains increase, olive tree health throughout Italy should improve increasing yield.

4.3 Precipitation Intensity and NDVI

Precipitation intensity in Calabria, Italy is increasing over time due to its overwhelming positive trends in the summer months. Winter precipitation intensity in the region is decreasing (Caloiero et al., 2011). Though more data would be necessary to point to more conclusive results, the negative trend between winter PI and early spring NDVI for Feudo Disisa demonstrates suggests that intense rains in flat orchards with moderate precipitation intensity that receive a moderate amount of annual rainfall negatively effects orchard health. Winter precipitation intensity is decreasing in parts of Italy which should positively effect the health of some orchards. All orchards showed a positive trend for summer precipitation intensity and late summer vegetation health. The significant positive trend for Frantoio de Carlo suggests that rains in the summer, the least intense rains of the year, are not intense enough to cause watterlogging and provided much needed water to dried orchards. Increasing precipitation intensity in the summer months should increase orchard vegetation health and therefore olive yield as long as precipitation events remain less intense than those occurring in the winter months now.

5 Conclusion

Winter precipitation intensity can negatively effect olive health at orchards under certain conditions. Summer precipitation is closely tied to harvest season olive tree health. Increasing summer precipitation and precipitation intensity will increase olive orchard NDVI. Predicted precipitation trends in the Mediterranean region - decreasing winter precipitation and precipitation intensity and increasing summer precipitation and precipitation intensity - could significantly promote the health of olive trees throughout Italy.

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