Shade Controls Hillside Olive Tree Growth

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Abstract

Olive orchards located on hillsides with steep gradients may display a decrease in fruit yield further down the hill due to wind, soil, and shade factors. Data collected on 29 October 2019 from the olive orchard Enotre located in Southern Italy supports this claim, as the average radial growth rates of trees increase as elevation increases. I hypothesize that shade is the primary cause of these differences in growth, while wind and soil have lesser or negligible effects. To test this hypothesis, I analyzed data from Enotre that included soil pH, soil color, drone imagery, and tree cores. From my results, I propose that attempts to decrease shade will significantly enhance efforts to increase radial tree growth, making shade consideration an essential component of planning hillside orchards.

Key Points:

1. Olive tree radial growth is greater at the top of hillsides than at the bottom
2. Competition for sunlight on shady slopes may be the cause of decreased growth rates
3. Strategies to increase sunlight on shady slopes may increase olive tree fruit yield

1 Introduction

Successful olive farming in highland regions with steep gradients requires the terracing of hillsides to guarantee olive tree stability. However, terracing may reduce the sunlight available to trees further down the hillside, which may decrease both oil yield and quality, as well as tree health (Melgar et al., 2009; Reale et al., 2019). I hypothesize that the resulting difference in sunlight received by each tree is the primary cause of differences in radial growth observed between olive trees of the same species located at different levels of the hillside at the orchard Enotre.

Radial growth rates are frequently used to represent tree health, and trees with decreased growth rates may have a higher probability of mortality than trees with greater growth rates (Das & Stephenson, 2015; Stephenson et al., 2011). Determining the causes of differences in radial growth is thus required to assist farmers in planning and planting hillside orchards in such a way that optimizes oil yield and quality (Singh & Kanwar, 2004; Steiner, 1986). This would enable olive farmers to maximize profits from olive orchards located on hillsides of known gradients. I will test my hypothesis that shade controls differences in olive tree growth between trees of the same species by analyzing the relative effects that shade, wind, and soil characteristics have on olive tree growth.

The current study focuses on the olive orchard Enotre located in Southern Italy (Easting 6538887 m, Northing 4328714 m). Enotre has the unique advantage of possessing trees of known age, making the calculation of average radial growth rates (cm/yr) possible. Although this study is relatively narrow in scope (Enotre contains only 3 hectares of land), I propose that the resulting conclusions may be extended to any orchard of known gradient.

2 Data and Methods

Data collected from the orchard Enotre in Southern Italy on 29 October 2019 include soil samples, tree height, tree diameter (at 20 cm), drone imagery, and tree cores. Soil samples were collected using small shovels and were stored in plastic bags. Soil pH values were recorded using a Hach HQ40d pH meter after soils had equilibrated for over 24 hours with deionized water. I used the Munsell Color System to calculate soil RGB values, which I converted into hue, saturation, and value (HSV) values for use in analysis. I elected to use the HSV color space as it is considered to be an optimal color space for analyzing soils, in addition to the fact that saturation values correlate highly with pH (Barman et al., 2018; Hernandez-Hernandez et al., 2016). HSV values for each soil sample were recorded three different times, and in an attempt to preserve accuracy, I only utilized the 43 (out of 84) soil samples in which at least two of the tree recorded values were identical.

Tree height measurements were obtained with a Nikon Forestry Pro Laser clinometer, and tree diameter measurements were obtained using a tape measure. Drone imagery was obtained with an eBee X drone flown to obtain a digital elevation model (DEM) and an orthophotomosaic. I utilized the drone imagery to identify and mark individual trees in the Enotre orchard and to calculate tree canopy area. I calculated tree canopy area by outlining each tree and finding the contained area. After each tree was marked, I used the corresponding coordinates to calculate the distance from each tree to its nearest neighbor.

Tree cores were collected using a 3-Thread Jim-Gem Increment Borer. Cores were collected approximately one meter from the ground and then stored in plastic straws. Trees were selected for coring based on their straightness, as well as location: I tried to obtain samples from all parts of the orchard. Following extraction, I glued the cores onto wood mounts with grooves, and then used an electric sander (with 120, 220, and 320 grit sandpaper) to flatten the cores for scanning. I used a portable Canon scanner to produce images of each core, from which I was able to identify the center by identifying the point at which rings begin to form circles (or semi-circles) in the wood. I then measured the distance from the center to the bark in order to obtain the total growth of each core and divided this measurement by each tree's age to calculate average growth per year.

I analyzed these data for correlations between variables by calculating the correlation coefficient and p values between each pair of variables. I identified four testable explanations for the correlation between elevation and tree growth. I then examined each factor's relationship with average tree growth, or if that was impossible due to data constraints, with elevation.

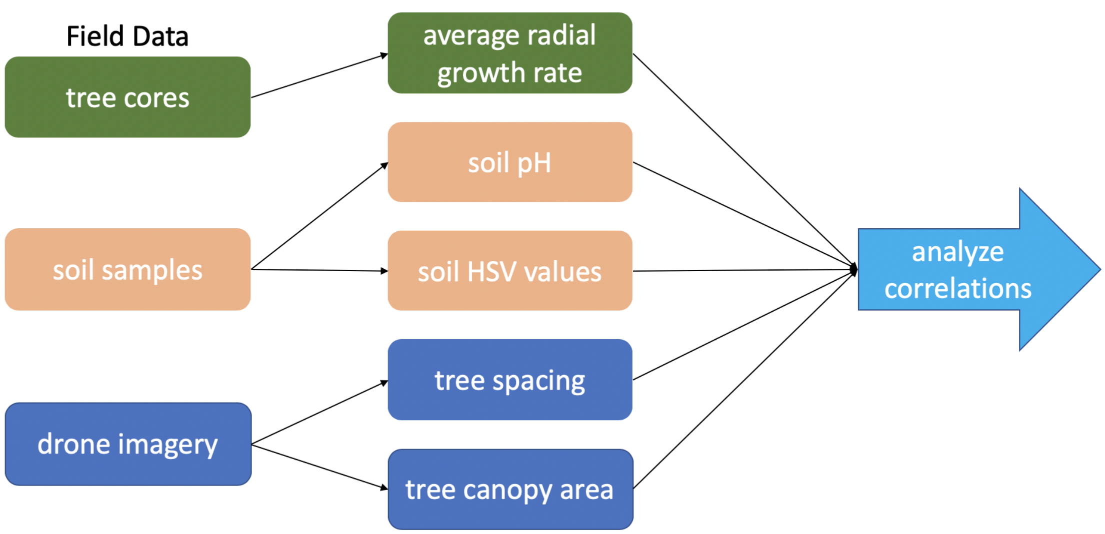

Figure 1: Sequence of steps required to use field data to analyze the relationships between different data.

To determine whether or not shade is increased further down the hillside, I relied upon other studies that attempted to quantify shade (Daniel Knapp, pers. comm., 2020) or sunlight (Buffo et al., 1973) on a given slope. To obtain exact results, future methods to measure the shade that each tree is covered in throughout the day could include modeling each tree onto the drone DEM in the form of hemispheres on sticks and then simulating shadows for hourly positions of the sun onto the model. Following the simulation, shadows could be identified on the basis of pixel brightness values, allowing one to determine the percentage of each tree covered in shade throughout the day.

3 Results

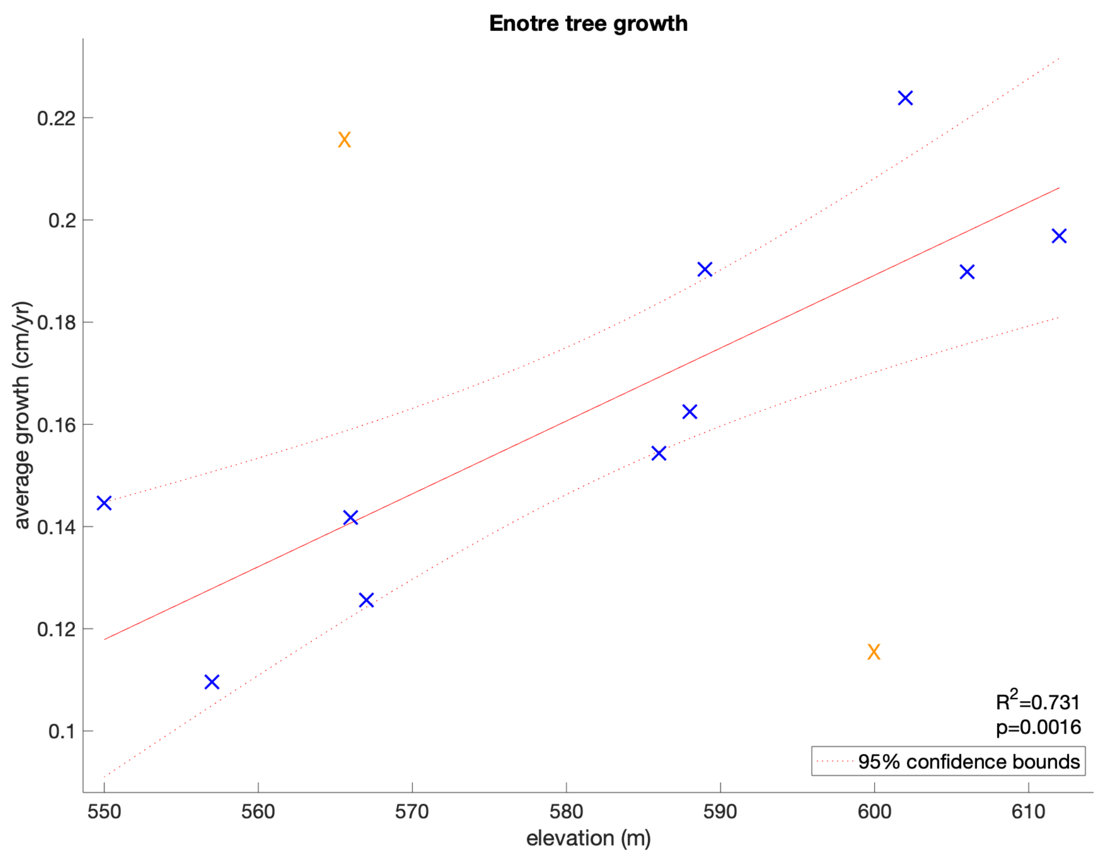

Figure 2: Average yearly growth and elevation for trees in Enotre with R^2 and p values recorded (the two outliers presented in orange were not included in these calculations). Note that for every 10 m increase in elevation, the average growth per year increases by approximately 0.02 cm. Growth is measured using analysis of tree cores collected 29 October 2019.

Olive trees in Enotre appear to grow more quickly the further up the hillside they are located. Although this analysis included data from less than 10% of the trees in Enotre, the P value of 0.0016 indicates that the relationship between elevation and olive tree growth observed in the 10 measured trees is likely indicative of a similar trend encompassing the entire orchard (Fig. 2). The two outliers removed from this analysis include one tree that experienced a relatively low average growth rate of 0.12 cm/yr while recording an elevation of 600 m and one tree that experienced a relatively high average growth rate of 0.21 cm/yr while recording an elevation of 570 m. I hypothesize that the first tree may be planted in an exceptionally dense area, while the second may be planted in a lesser populated area, allowing it to experience greater growth. I found support for my hypothesis by examining the distance to the nearest neighboring tree of each tree. Including the two outliers in the analysis still produces significant evidence of a correlation between average

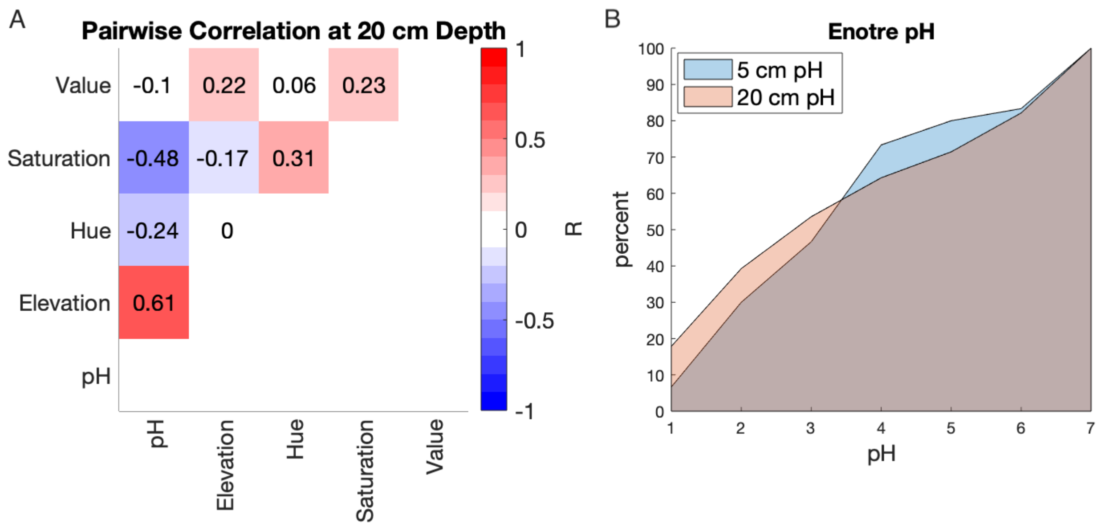

Figure 3: (a) Correlation coefficients for hue, saturation, value (HSV), elevation, and pH values in Enotre. Note that the two correlation coefficients greatest in magnitude are between pH and elevation, and pH and saturation. (b) Cumulative histograms of pH at 5 and 20 cm depths in Enotre. Note that there are a greater number of 20 cm pH values than 5 cm pH values at lower than 3.5 pH.

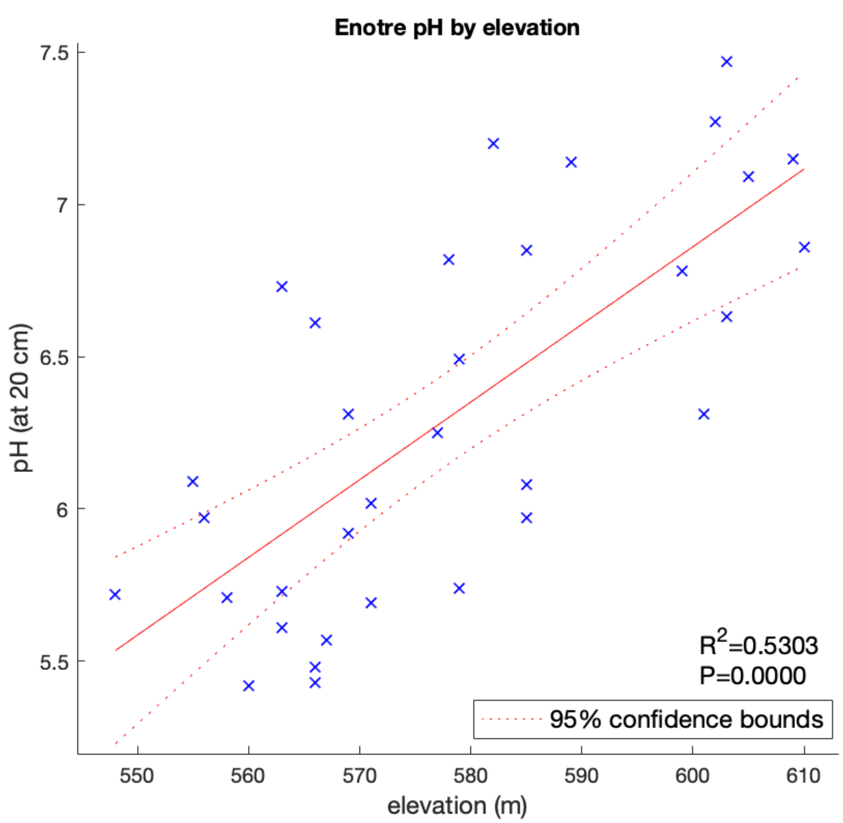

Figure 4: Relationship between elevation and pH at 20 cm recorded at 35 sites in Enotre (disregarding 3 outliers). The R^2 and p values suggest that there is significant correlation between elevation and pH, as pH levels increase with increases in elevation. Elevation is a more accurate predictor of soil pH at 20 cm than HSV, tree height, or tree diameter. However, there is little correlation between elevation and soil pH at 5 cm.

tree growth and elevation: correlation coefficient of 0.516 and p value of 0.0854. However, both elevation and average radial growth are uncorrelated with tree height.

Enotre soil pH values 20 cm below the surface are significantly correlated with elevation (R=0.61), and soil pH values at 20 cm increase as elevation increases (Fig. 3a). Removing 3 outliers increases the correlation coefficient to 0.73 (Fig. 4). Soil pH values at 5 cm below the surface and elevation are not significantly correlated: R=0.26.

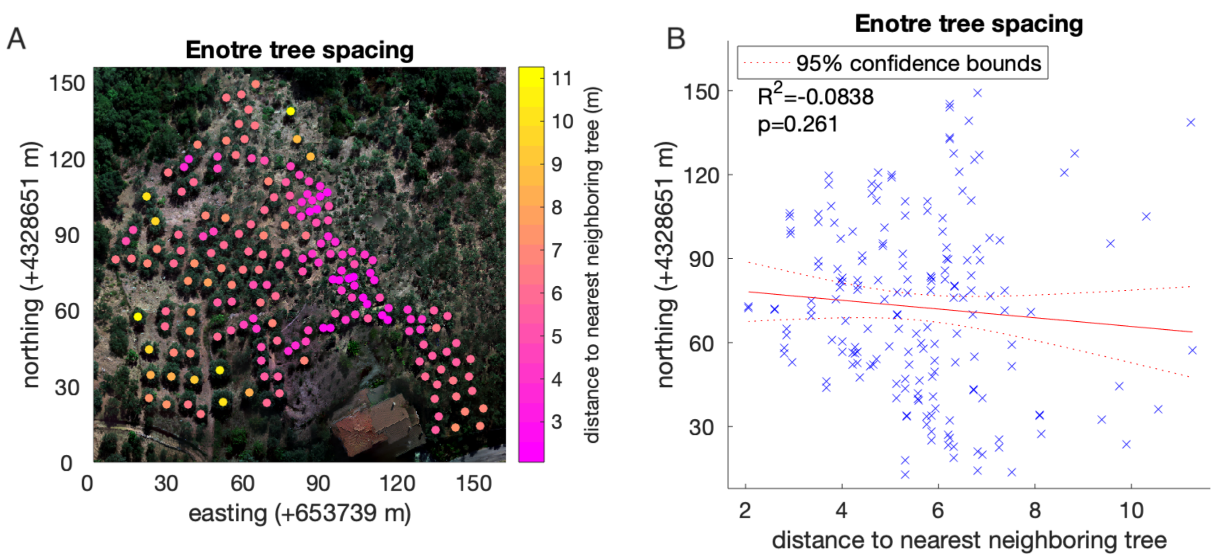

Figure 5: (a) Distance to the nearest neighboring tree of each tree in Enotre. The majority of trees have a nearest neighbor that is less than 5 m away. Note that the point (0,0) represents the coordinates 653739 easting, 4328651 northing. (b) Relationship between distance to the nearest neighboring tree and tree location (represented by northing) at Enotre. Note the low R^2 and high p values. There is little to no correlation between tree spacing and northing.

Soil saturation values at both 5 and 20 cm depths appear to be negatively correlated with soil pH at 20 cm (R=-0.47 and -0.48 respectively) but not to elevation (Fig. 3a.). With the exception of saturation and pH values, there are no significant correlations between any of soil pH, HSV values, and elevation at 5 cm below the surface.

The mean distance to the nearest neighboring tree for olive trees in Enotre is 5.55 m. It appears that the distance between trees is least in the area surrounding 100 easting, 90 northing (plus 653739 easting, 4328651 northing) (Fig. 5a). There is little to no correlation between the distance to the nearest neighboring tree and tree location in the northing direction (Fig. 5b). The residual of tree spacing and northing appears to be entirely irregular, and the distance to the nearest tree of olive trees in Enotre does not appear to follow any meaningful pattern (Fig. 5b).

Shade and elevation at Enotre are estimated to be significantly negatively correlated (R=-0.78): shade increases further down the hillside (Daniel Knapp, pers. comm., 2020).

4 Discussion

Because the difference in elevation of trees at Enotre is less than 80 m, direct effects of elevation (such as differences in temperature and air pressures) are miniscule, and thus there must be indirect effects of elevation present that cause this trend. I identified four possible explanations for this observation:

1. Olive trees at the top of the hillside are exposed to more wind, causing them to grow wider and shorter than trees further down the hillside to resist the wind.
2. Soil characteristics differ from the top of the hillside to the bottom, granting an advantage to trees at a specific level.
3. Olive tree spacing is not uniform throughout the hillside, creating differences in the competition that each tree must face.
4. The gradient of the slope causes trees further down the hillside to be covered in a greater amount of shade, reducing growth.

Because the measured values of average tree growth only account for radial growth and not upward growth, shorter yet wider trees would appear to have experienced greater growth than taller and thinner trees. However, there is no correlation between elevation and olive tree height. Olive tree height measurements appear to be randomly distributed throughout the Enotre orchard, and olive trees at the top of the hillside are not shorter than trees further down the hillside. Unfortunately, this hypothesis is complicated by the fact that height values of Enotre trees may be suspect due to measurement inaccuracies.

To further analyze the hypothesis that wind causes trees at the top of the hill to grow wider, I studied tree canopy areas. For the 12 cored trees, there is no correlation between tree canopy area and elevation, while this hypothesis would expect tree canopy areas to be greater further up the hill. Thus, although the idea that olive trees at the top of the hillside grow outwards at greater rates than those further down the hillside in response to wind cannot be entirely eliminated due to possible data inaccuracies, tree canopy measurements suggest that an increased exposure to wind is not the primary cause of increased outward growth.

Soil pH values slightly below 6.5 (down to 5.5) generally optimize tree growth as greater nutrients exist in soils between 5.5-6.5 pH than in soils above 6.5 pH: other species in the family Oleaceae, includeing ash, forsynthia, lilac, and fringetrees, all prefer slightly acidic soil (Bassuk & Trowbridge, 2013). Although there is little to no literature describing the optimal soil pH for olive tree growth, it is likely that olive trees prefer slightly acidic soil as this is the preference of most other trees, including the olive tree's relatives.

However, because Enotre soil pH at 20 cm increases from 5.5 pH to 7.5 pH as elevation increases, one would expect soil pH to enhance tree growth further down the hillside rather than at the top of the hillside. It appears then that either olive trees are unique in the family Oleaceae and prefer less acidic soils than other trees; that soil pH has little to no impact on tree growth; or that olive trees do indeed prefer slightly acidic pH values as expected, but that a separate factor has a greater impact on tree growth than does soil pH and completely reverses any effects that soil pH may have had on tree growth. Although the first two possibilities cannot be eliminated entirely, it is probable that olive trees do prefer slightly acidic lower pH values like most other trees, and the hypothesis that soil pH is responsible for changes average tree growth with elevation may be incorrect.

Competition between trees can be quantified using the distance from each tree to the nearest neighboring tree (Pielou, 1962). Thus, the hypothesis that there is greater competition between trees at the bottom of the hillside would be supported if Enotre olive trees were more clustered further down the hill than at the top; however, this is not the case. Because the hillside is south-facing, and elevation is relatively constant with variations in easting (when northing remains constant), analyzing changes in tree spacing with respect to northing can serve as a proxy for analyzing changes in tree spacing with respect to elevation. There is no correlation between tree spacing and northing, and thus there is no correlation between tree spacing and elevation. Trees are no more clustered further down the hillside than at the top, and the competition that each tree must face varies at each level of the hillside. In fact, Enotre olive trees furthest down the hillside have a greater distance to the nearest neighboring tree than do many trees further up the hillside (Fig. 5a). Thus, the observed relationship between elevation and average tree growth cannot be explained by patterns in tree spacing.

The hypothesis that increased shade further down the slope causes the difference in radial growth between trees is supported by the highly negative correlation between shade and elevation estimated by Knapp (2020). This hypothesis is also consistent with the conclusions that shade decreases olive tree health, which is related to growth (Das & Stephenson, 2015; Reale et al., 2019). Although, the method used by Knapp (2020) considered a sample of less than 1% of the points at Enotre, bringing into question the method's accuracy in quantifying shade, the highly negative correlation between suggests that this sample may be indicative of the entire orchard. Further simulation as described in Section 2 would be required to confirm or disprove Knapp's results.

Nevertheless, the rejection of hypotheses one through three implies that differences in shade do indeed cause the decreased growth of trees further down the hillside. If this hypothesis is correct, planning and planting orchards in a way that minimizes shade would optimize olive tree growth. Farmers may achieve this through a process of strategically pruning trees further up the slope, allowing increased sunlight to penetrate to trees below (DeSalvador & DeJong, 1989). In addition, farmers may attempt to increase the crown area of trees further down the slope in order to enable such trees to obtain increased sunlight (Lang et al., 2010).

5 Conclusions

The observed relationship between elevation and average tree growth is not caused by tree responses to wind exposure, differences in soil, nor patterns in tree spacing. Through this process of elimination, it is likely that shade is the primary cause of the decreased growth of trees further down the hillside. Confirmation of this conclusion can be reached through further analysis simulating shadows onto the entire Enotre orchard.

Olive farmers may use the idea that shade decreases olive tree growth by attempting to increase sunlight available to trees further down the hillside through altering tree morphology using methods such as pruning. Doing so would increase olive tree oil yield and quality, as well as tree health, leading to increased profits.

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