Agricultural Liming is a Solution for Olive Tree Growth Deficits in Southern Italy

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Abstract

Over the years, changes in the Mediterranean climate have caused olive farmers to struggle in keeping up with a growing demand for the fruit's oil. The situation is only expected to worsen, and farmers need to better control the soil of their orchards in order to maximize olive output. This study tests how soil chemistry affects olive tree growth and canopy health. The collected data suggest that acidic soil, being generally deficient in calcium, yields shorter trees with narrower trunks. Furthermore, there is no correlation between soil iron content (measured through soil redness) and tree canopy health (measured through NDVI). As a result of these observations, agricultural liming, which increases soil pH and calcium content, emerges as the most promising strategy for increasing tree size and olive output.

Key Points:

1. Remote sensing and field data quantify olive orchard health in Southern Italy
2. Calcium deficiency in acidic soils inhibits proper olive tree growth
3. Iron content in soil has no detectable effect on olive tree health

1 Introduction

In recent years, a growing appreciation for the health benefits of olive oil has caused the global demand for this product to skyrocket (Sengupta, 2017). At the same time, increased droughts in the Mediterranean have caused olive farmers to struggle keeping up with such high demand (Hoerling et al., 2012). Without proper precipitation, olive trees fail to grow at their regular pace, and total olive oil output is consequently reduced. For example, in Italy alone, last year's olive oil output was down 20% from the average in the previous decade (Sengupta, 2017). As global warming continues to affect the world's climate, the Mediterranean is expected to keep suffering from droughts (Giorgi & Lionello, 2008), and regional olive oil production will therefore face many challenges. To prevent this decline and keep up with global demand, olive farmers need to find ways to cope with the decrease in precipitation. A promising solution revolves around manipulating the soil on which the trees are planted in order to maximize tree growth and olive output. However, very little is known about how olive trees specifically respond to different elements of the soil, and it is therefore difficult to select an optimal soil for these plants.

The purpose of this study is to provide farmers with this necessary information on ideal soil conditions for olive trees. Because calcium and iron are two of the most important nutrients for plants (Gregory & Nortcliff, 2013), and their concentrations can be easily detected in soil, those elements are the main focus of my study. More specifically, the study evaluates how soil acidity and color, two indicators of calcium and iron content, affect olive tree size (height and diameter) and health (canopy NDVI). My observations yield a comprehensive understanding of the soil characteristics that are of particular interest to olive tree farmers.

2 Data and Methods

All data presented were collected by a group of Princeton University undergraduate students at Enotre, an olive grove in Mesoraca, Italy. The orchard contained hundreds of trees that were all planted during the same year, and had therefore been growing for equal amounts of time; these constant ages allowed our group to attribute differences in tree dimensions to other variables, such as surrounding soil quality. Our field data collection can be separated into three different categories: measurement of tree dimensions, evaluation of soil chemistry, and analysis of canopy health.

For the first type of data collection, tree dimensions, we took individual measurements of dozens of trees in the orchard. To measure the heights of the trees, we used a clinometer (Nikon Forestry Pro Laser Rangefinder) whenever possible. For trees that were too close to each other to measure using the clinometer, we measured them by hand using measuring sticks. For the tree diameters, we used a measuring tape to wrap around the tree trunk, taking all our measurements at a height of 20 cm above the ground.

The soil data collection consisted of randomly selecting trees at the orchard, and then taking soil samples. We filled 1 L bags halfway with soil taken at depths of 5 cm and 20 cm, 1 m north from the trunk of a tree. After collecting all the soil samples, we used a soil color sensor (Munsell CAPSURE Color Matching Tool) to evaluate the sample's color. Afterwards, we diluted the soil in deionized water, and let it rest overnight. The following day, we used a pH meter (Hach intelliCAL pH Meter) to measure the diluted soil's acidity, given its hydrogen ion concentration:

$$pH = -log([\mathrm{H}^{+}]). \tag{1}$$

The Munsell color values were converted to RGB for iron oxide content analysis. Because yellow and red soils indicate a high presence of iron oxides (Weill & Brady, 2016), I created a Yellow-Red Index (YRI) to measure the relative redness and yellowness of a soil sample, given its RGB values:

$$YRI = \frac{R + G - B}{R + G + B}. \tag{2}$$

Last, evaluating the health of each tree canopy required the collection of overhead imagery. We flew a Sensefly eBee X drone with a MicaSense Rededge MX camera and took images of the entire orchard to accomplish this task. On the ground, we marked the GPS coordinates 1 m north of every sampled tree in order to link the tree's image with its soil sample and dimensions. We used a Garmin GPSMap 60c to retrieve our coordinates.

In order to calibrate the GPS measurements to the drone image, we established three control points at the orchard. Throughout the day, we recorded numerous measurements at these same control points, and later identified their true location using the GPS coordinates from the drone image. By evaluating the deviations of the ground measurements from this established, true location, I was able to identify necessary corrections to our GPS measurements, and report an average error (Figure 1). After calibrating all of our GPS coordinates, I then plotted them on top of the drone imagery, and was able to single out which canopy corresponded to which coordinate. I defined a polygon around each sampled tree's canopy (Figure 1), and retrieved the RGB and near-infrared (NIR) values of each pixel within the polygon. In order to assess the health of the tree canopies, I used the normalized difference vegetation index (NDVI). A ratio computed using Equation 3, NDVI is the most commonly used vegetation index to evaluate the relative health and condition of plants from drone or satellite imagery (Matsushita et al., 2007):

$$NDVI = \frac{NIR - R}{NIR + R}. \tag{3}$$

After acquiring all the NDVI values at each pixel within the polygon, their mean was computed in order to get an indication of the average health of each tree canopy.

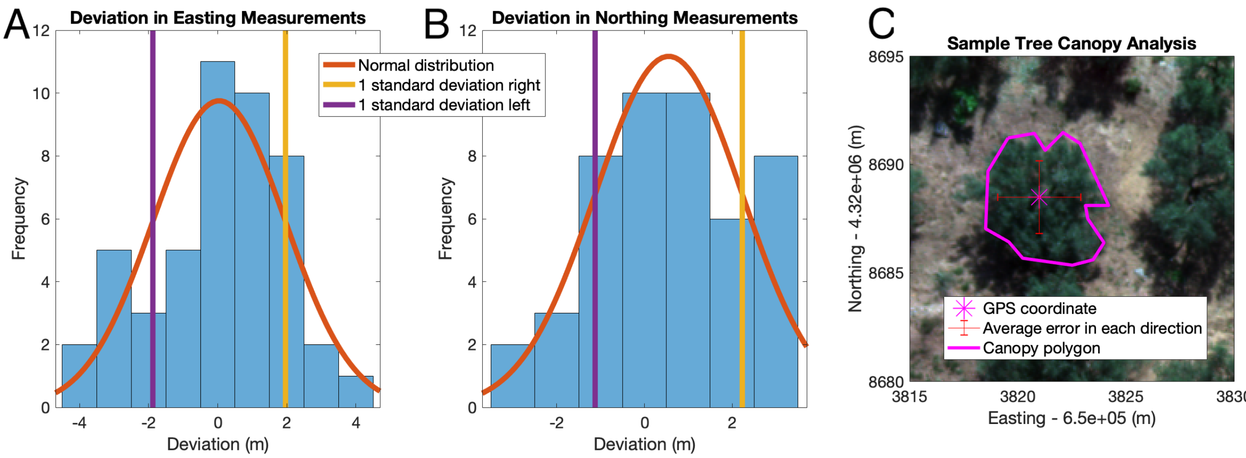

Figure 1: Histograms displaying GPS control point measurement deviations from their true location established by drone. A) Easting histogram centers at 0 (needs no correction), and has a standard deviation (average error) of 1.9 m. B) Northing histogram centers at 0.5 (needs -0.5 m correction), and has a standard deviation (average error) of 1.7 m. An additional 1 m was subtracted from each northing value because all measurements were taken 1 m north of each tree trunk. C) After applying the corrections and considering the average error, it is very easy to detect which coordinate corresponds to which tree canopy. Canopy polygon drawn to define range of pixels being considered as part of the canopy.

3 Results

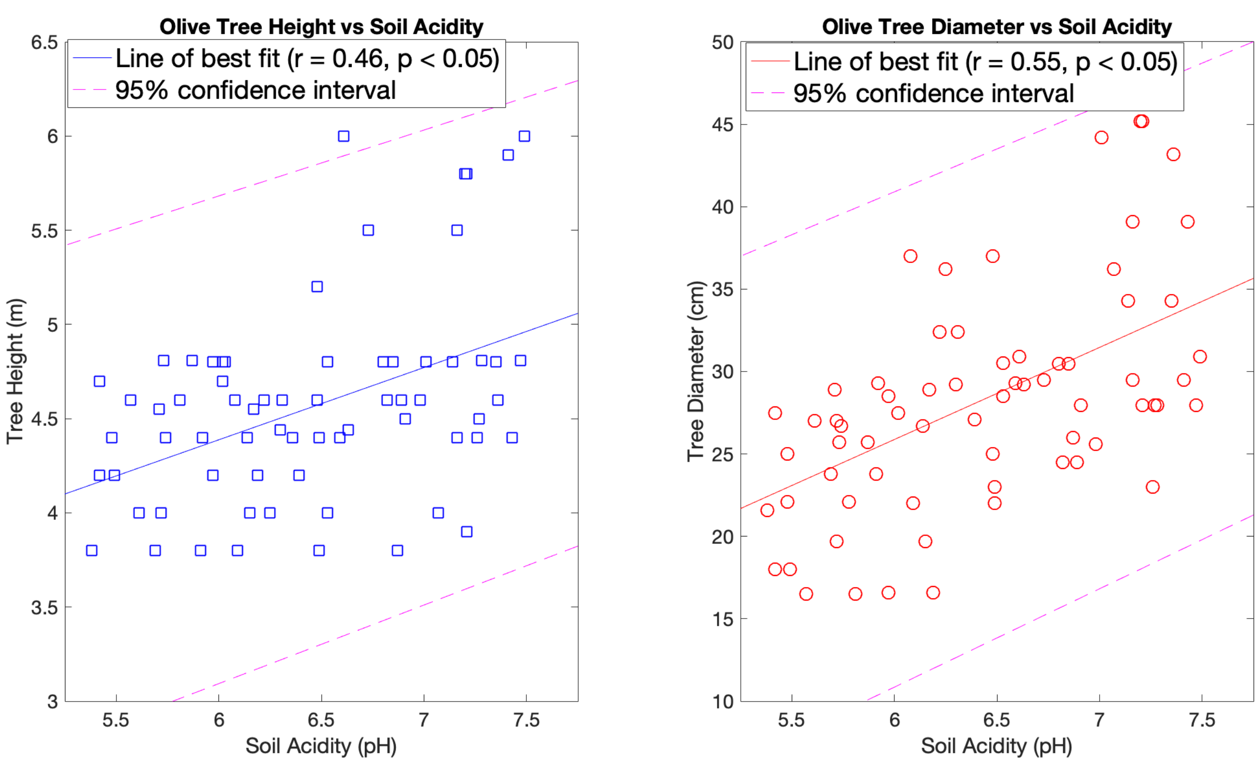

Figure 2: Olive tree height (recorded by laser clinometer) and diameter (recorded by measuring tape) plotted against acidity of the soil on which the tree was planted. Least-squares regression lines and confidence intervals plotted alongside data points. Residual histograms for both variables show symmetric distributions about the mean (which is 0), implying that the lines are adequate fits for the data.

Figure 2 shows clear positive correlations between both sets of tree dimensions and soil acidity at the orchard. To better understand why this correlation exists, it is important to compare the color of the soil samples at varying acidities (Figure 3). Doing so will help determine what underlying compounds and elements are affecting the growth rates of the olive trees.

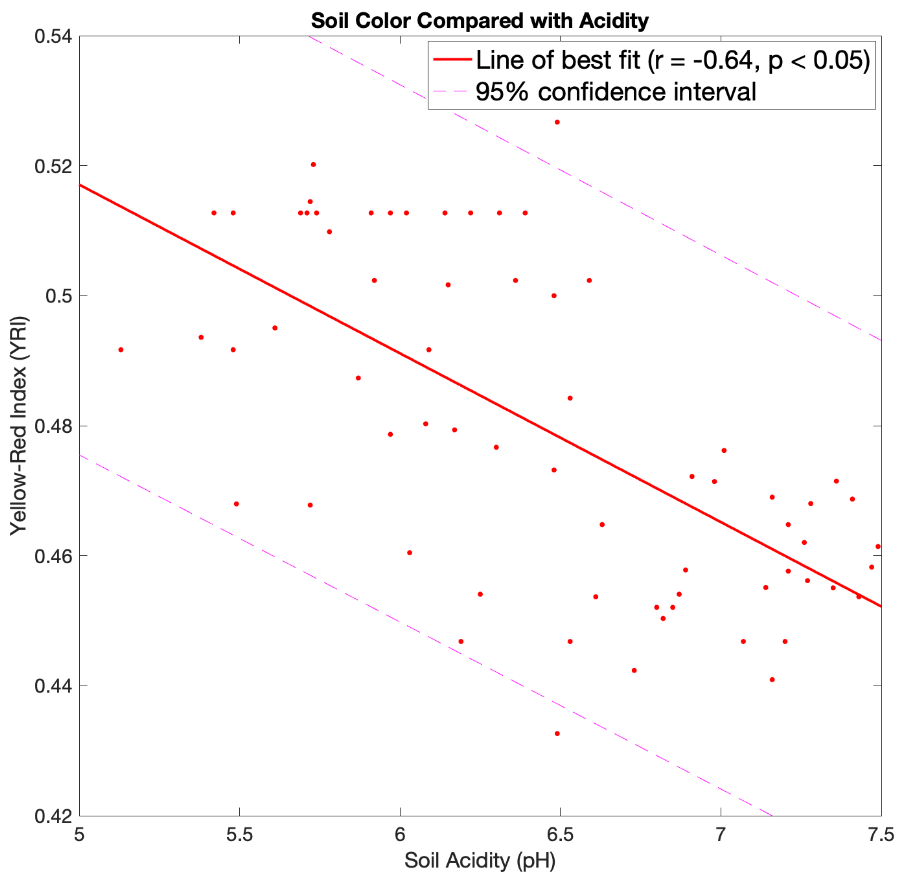

Figure 3: Yellow-red index values (Equation 2) for soil samples at different soil acidities. Least-squares regression line and confidence interval plotted alongside data points. Residual histogram is symmetric and therefore implies that the regression line is a valid representation of the data. This relationship implies that iron oxides (found in redder, yellower soils), are more abundant in acidic soil.

Having tested the relationships between soil acidity, tree growth, and soil color, the only missing piece of analysis to completely test my hypothesis is an evaluation of tree canopy health. For this experiment, I also decided to test the effect of tree spacing, as overcrowding in an orchard can deteriorate the health of the trees (León et al., 2007). A fellow Princeton researcher, Lauren Blackburn, determined that the western section of the orchard had more tightly packed trees, while the eastern section had greater spacing (Lauren Blackburn, pers. comm., 2019). Plotting both soil color and easting in Figure 4 allows us to determine the relative importance of iron content and tree spacing, two separate variables of interest for farmers, in promoting healthy photosynthesis.

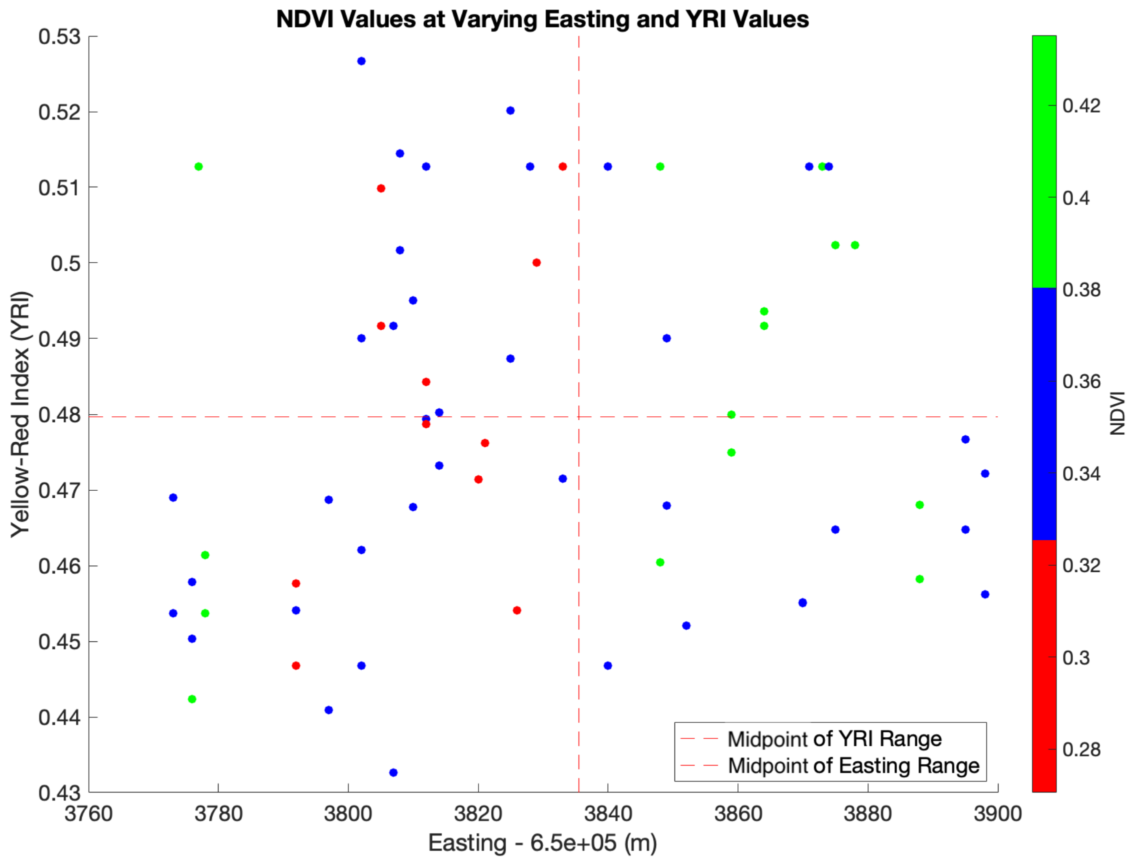

Figure 4: The effects of soil iron oxide content (measured through YRI) and tree spacing (measured through easting) on olive tree photosynthesis. Higher NDVI values (Equation 3), implying healthier vegetation, used to quantify the quality of photosynthesis. Note how the majority of high NDVI values occur on the right half of the figure (mean NDVI = 0.38), while lower values are all in the left half of the figure (mean NDVI = 0.34). No such distinction occurs in the top and bottom halves of the figure, where the mean NDVI is 0.34 in both sections. The correlation coefficient between soil color and tree canopy NDVI is 0.05, further implying little correlation. Ultimately, adequate tree spacing has a much greater effect on photosynthetic success than iron oxide content.

Figure 4 demonstrates that farmers should not be worried about needing iron supplements in their orchards, and that providing enough spacing between trees is a better strategy for promoting overall tree health. To ensure that these results are accurate, I decided to test the sensitivity of this correlation between iron content and canopy health to errors in measurement. Errors in canopy assessment were quantified by obtaining the standard deviation of the NDVIs of all pixels in each canopy. Then, because we measured the color of each soil sample three times, the range of YRI values obtained from these three measurements were used as an indication of the error in soil color. Performing a weighted correlation analysis, which gives more "weight" to measurements with smaller errors, yielded a correlation coefficient of 0.11. Although this value is slightly higher than the non-weighted correlation coefficient, it is still statistically insignificant, reinforcing the lack of correlation between these two variables.

4 Discussion

To begin the process of determining which qualities make a soil optimal for olive tree orchards, we must combine and analyze the results seen in the previous section.

Figure 2 begins by demonstrating that olive trees grow less effectively, in both vertical and radial directions, when planted in acidic soil. Typical issues regarding plant growth on acidic soil include aluminum toxicity and calcium ion deficiency (Pierre, 1931). The former issue occurs because aluminum is more soluble at lower pH, and its free ion concentrations are therefore greater in acidic soils (Delhaize & Ryan, 1995). When that is the case, plant roots avoid elongating in the direction of the toxic aluminum, and the growth of the plant is thereby impeded (Gregory & Nortcliff, 2013). On the other hand, unlike aluminum, calcium ion availability in acidic soils tends to be low (Bordeleau & Prévost, 1994). This deficiency is an issue for plants because calcium is a valuable nutrient that makes up cell walls (White & Broadley, 2003), and its presence in soil is a valuable promoter of root elongation (Gregory & Nortcliff, 2013). Its absence in acidic soil, therefore, prevents olive trees from growing to their full size.

Having established these two issues as common problems in acidic soil, it is now necessary to determine which of them is most prominent in our orchard. Aluminum toxicity only tends to occur at pH values below 5 (Delhaize & Ryan, 1995), and since the lowest measured pH at the orchard was 5.13, it is unlikely to be affecting our olive trees. Calcium deficiency, therefore, is the most probable cause for the observed reduction in olive tree growth on acidic soil.

To test this prediction, we can analyze the relationship between soil color and soil acidity in Figure 3. High presence of calcium compounds in soil give it a whiter color (Escadafal, 1993), which would yield a lower YRI value due to decreased redness from iron oxides. In Figure 3, we see this very trend develop as the YRI drops in more basic (higher pH) soils. Therefore, the data confirm that acidic soils have lower amounts of calcium, which is likely leading the trees to have reduced growth.

Having determined the importance of calcium for proper olive tree growth, it is now time to analyze the other element of interest in this study: iron. Iron is an important element that makes part of the structures that allow plants to perform photosynthesis (Oijen et al., 2004). More specifically, it is contained within the chloroplasts of plants, and therefore helps give leaves their green color (Gregory & Nortcliff, 2013). As a result, iron deficiencies in plants are easily detected because the leaves lose their natural, green color.

Figure 3 demonstrates that iron, quantified through YRI (Equation 2), is more abundant in soils with greater acidity. This trend has been seen in numerous other studies, such as those by Gregory & Nortcliff (2013) and Wallace et al. (1980). However, in order to evaluate how this amount of available iron affects our olive trees, we must also consider the ability of the roots to absorb the nutrient. Morrissey & Guerinot (2009) explain that when it comes to iron, absorption occurs more easily after the ferric (Fe^{3+}) ion has been removed from the attached oxide:

$$Fe_2O_3 + 6\,H^+ \longrightarrow 2\,Fe^{3+} + 3\,H_2O. \tag{4}$$

Since this process is facilitated by hydrogen ions, iron intake occurs more readily in soils with low pH (see Equation 1 to see how pH and H^+ concentration relate). Therefore, not only do acidic soils at the orchard contain more iron compounds (Figure 3), but they also increase the tree's access to this nutrient.

Combining our observations on calcium and iron behavior at the orchard yields a particularly concerning realization: both these nutrients have optimal concentrations in different types of soils. In other words, farmers will have to sacrifice one in order to maximize the other. This is a typical issue in agriculture, and different species of plants display preferences towards different elements (Truog, 1918). There is litte information, however, on how olive trees respond specifically. This study already demonstrated that calcium availability correlates with taller and thicker olive trees (Figure 2), so it is now fitting to analyze how iron availability in the soil affects the health of the tree canopies.

Figure 4 demonstrates the lack of correlation between iron oxide content in the soil and average tree canopy health. In fact, it also implies that tree spacing in the orchard is a better promoter of plant health than soil iron content. Therefore, farmers are better off ensuring that all their trees have enough space for growth and development, instead of applying any sort of iron supplements to their soil. It is relatively unclear why the olive trees are practically unaffected by changes in soil iron content, but the most likely explanation is that there is already ample iron in the soil of this region of Italy; in other words, iron is not the limiting nutrient in the soil.

Recognizing the underlying chemicals that affect olive tree growth and metabolism at the orchard allows me to now recommend a method by which these farmers can improve their olive output. Because calcium deficiency and soil acidity are the major issues at the orchard, soil liming is the most promising solution for the trees. Liming consists of applying calcium compounds (such as calcium carbonate) to soils in order to decrease their acidity (Robson, 1989):

$$CaCO_3 + 2\,H^+ \longrightarrow Ca^{2+} + CO_2 + H_2O. \tag{5}$$

Equation 5 demonstrates that the process of liming not only neutralizes free hydrogen ions, thereby increasing pH (Equation 1), but also increases the concentration of calcium ions for olive tree roots to absorb. This process is therefore an ideal solution for olive tree farmers in this region of Italy. Trees planted on soils with this fertilizer treatment can be expected to display greater vertical and radial growth, ultimately producing a greater quantity of olives for harvest.

5 Conclusions

While the global demand for olive oil is rapidly increasing, recurring droughts in the Mediterranean are causing olive farmers to struggle in matching the demand. Possible ways to combat the decrease in precipitation include improving the manipulation of soil at olive orchards, and to facilitate this process, my study examined the ways in which soil affects olive trees. This study demonstrates that acidic soils often exhibit calcium deficiency, and trees planted on these soils demonstrate decreased growth and development. To fix this issue, farmers must first identify acidic soil by looking for regions of soil that stand out as more yellow or red than their surroundings. Farmers should lime these areas, thereby increasing the pH and the calcium availability. Although this solution could lower the amount of available iron (because of increased pH), this reduction is not a concern for farmers as fluctuations in iron soil concentration led to no significant changes in overall tree health. If farmers are concerned about the health of their tree canopies, they should instead consider increasing the spacing between their trees, thereby allowing adequate access to nutrients.

6 Acknowledgements

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