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Precision conservation of *Olea europaea* with thermal imaging techniques

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Abstract Olive tree (*Olea europea*) groves are not only typical Mediterranean ecosystems but also traditional agricultural systems supporting a significant range of ecosystem services. Over the last decades, olive tree conservation has become a priority for EU agro-environmental policy, focusing on agricultural landscape, olive-oil quality and local agro-economics. Precision agriculture, i.e. a set of analysis techniques combining multi-sensor systems, is used mainly in increasing productivity, though it can sufficiently support conservation strategies, resulting in a new research field called precision conservation. In this research, ground thermal imaging was used to study the olive trees' health and productivity. Approximately 70 trees were selected and photographed in two different field areas on Lesvos Island, Greece. Environmental parameters, cultivation practices, structural characteristics and productivity of these trees were recorded. The infrared-thermal (IRT) images of each tree were analyzed, and linear regression analysis was performed to detect key variables of the dataset. Results showed that both healthy and under stress olive trees could be detected through thermal imaging, a technique that facilitates conservation practices concerning olive groves. Significant correlation between productivity and thermography was partially detected. For better productivity estimation, future research will focus on analytical production traceability and temporal cultivation practices.

Keywords: ground remote sensing, olive tree, environmental stress, agricultural production

1. Introduction

Olive tree (*Olea europea*) groves are not only typical Mediterranean ecosystems but also traditional agricultural systems supporting a significant range of ecosystem services (Solomou et al. 2012). Furthermore, olive trees are one of the most important vegetation species concerning agricultural economy in the Mediterranean region (Solomou and Sfougaris 2011), and in Greece particularly, there are more than 150 million trees. Over the last decades, olive tree conservation has become a priority for EU agro-environmental policy, focusing on agricultural landscape, olive-oil quality and local agro-economics (Lefebvre et al. 2012). Specifically, the value of traditional olive groves is widely recognized as cultivation practices allow the development of deep grooves and broad canopies in olive trees, which create microhabitats that support biodiversity (Davy et al. 2007). However, this practice is posing risks because, as olive trees age, their short and large trunks which develop multiple branches with cascading twigs, acquire cracks, splits, cavities, as well as associated decay and thus, many trees are less productive. Additionally, they can be lost prematurely due to (a) insect and disease infestation, (b) environmental stress from drought and low soil fertility, and (c) structural failure. For trees with structural defects, even though their surface appears healthy, these structural changes could cause, overtime, significant damage to the whole plant (Catena and Catena 2008).

Techniques, that could assess the overall tree condition and its structural defects, are important in order to develop an effective management plan for their protection and maintenance. For this purpose, Precision Agriculture, i.e. a set of analysis techniques combining multi-sensor systems, is used mainly in increasing productivity, though it can sufficiently support conservation strategies, resulting in a new research field called Precision Conservation (Berry et al. 2003). Several methodologies (destructive and non-destructive) have been applied to measure tree health, which are evaluated by the accuracy of assessing wood decay as well as their practical usefulness (Ishimwe et al. 2014). A non - destructive technique for evaluating tree health at ground level is thermal imaging (Ouis 2003), which is a type of active ground optical remote sensing, a fast growing technique and potentially an important tool for applications in various fields of environmental science. Specifically, it can be used to measure the viability of seeds and seedlings, to recognize disturbances, and to evaluate plants' growth (Dragavtsev and Nartov 2015). Moreover, it contributes to water loss (Ballester et al. 2013), assessment of soil salinity (Dragavtsev and Nartov 2015), recognition of thermoregulatory mechanisms of arboreal mammals (McCafferty 2013; Briscoe et al. 2014), detection of diseases in forest systems (Eitel et al. 2010; García-Tejero et al. 2012), and health assessment of various vegetation types (Catena and Catena 2008). Generally in trees, thermal imaging detects the distribution of tree trunk surface temperature (Burcham et al. 2012). An uneven temperature distribution indicates a structural defect in the tree. This difference in surface temperature between healthy and damaged tree trunk areas depends on the different thermal conductivity. This research focuses on assessing olive trees' health associated with their productivity, by using infrared thermography, a well-established non-destructive technique, which allows detailed inspection of their surface.

2. Materials and Methods

2.1 Materials and field research

For the purpose of this study, data from olive tree groves on Lesvos Island, which is located in the Northeast Aegean Sea, Greece, were collected. The island's olive groves, covering more than 80% of its agricultural area, are considered the main driving force of its rural economy (Kizos and Koulouri 2006). Two traditional olive grove sites were selected, in Pyrgi (39º05’51.1’’N, 26º30’48.2’’E) and in Agiasos (39º06’28.9’’N, 26º21’48.5’’E), with an area of 18000 m^2 and 14000 m^2 respectively. The Pyrgi grove, at an altitude of 10 m, is located within the Natura 2000 site GR4110004 while the Agiasos grove, at an altitude of 230 m, lies in the boundaries of Natura 2000 site GR4110011. Even though the climate of these sites is typically Mediterranean (warm, dry summers and cool, rainy winters), differentiations, due to topography variations, were observed. The field sites were surveyed from January to March 2017, after the olive harvesting season. At each site (a) topographical features (b) climatic conditions of the sampling period, and (c) cultivation practices, were recorded. A set of 70 olive trees (35 in each site) were selected by random sampling, in which specific characteristic features such as height, trunk diameter, ratio of tree branches (number of productive tree branches per total tree branches), number of structural defects, and productivity were measured. Thermal imaging was carried out, using a Testo 875-1 IR camera. The surface of each tree trunk and its branches were photographed during suitable environmental conditions (absence of rain, low wind speed) at a specific distance (5.0 m), height (1.3 m) and angle (90°).

2.2 Analysis of thermal images

The collected IR images were organized into a multilevel database, which included individual trees, sub-groups and the overall study area, while a combination of these images formed various thermal maps for each level, respectively. Each IR image, was calibrated and processed, according to the microclimate of the sites. The processed images were processed with Quantum GIS software (v.2.18.6) in order to discrete the areas of interest (tree trunks and branches) from other objects included in the IR images so to identify the temperature distribution and thus classify these areas. Additionally, (a) the mean and median temperature per tree, (b) the temperature range of the trunk surface in relation to the ambient temperature and (c) the standard deviation of temperature distribution were measured. The olive tree trunk surface temperatures were analyzed and those with similar temperature values were defined, focusing on the uneven temperature surface patches which indicate structural disturbances and irrigation stress (Figure 1).

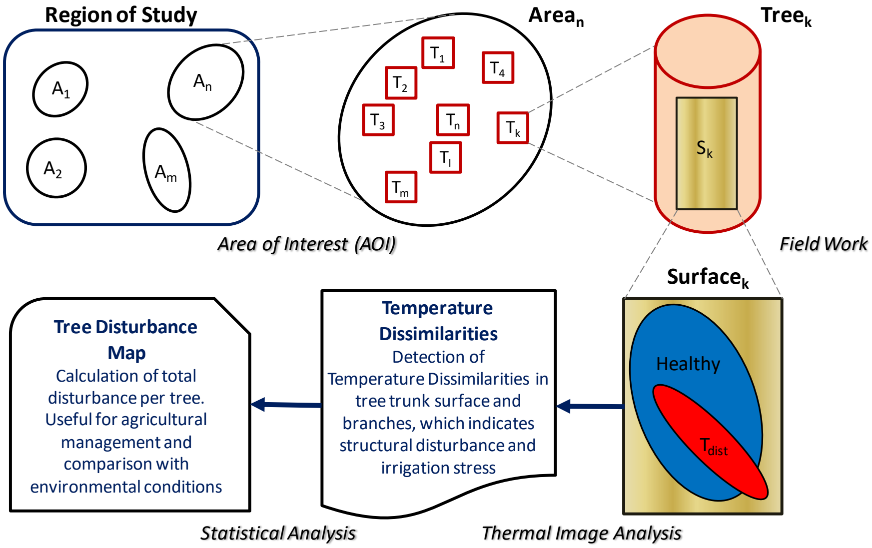

Figure 1. Methodological framework of olive grove analysis that includes: the area of interest (AOI), the field work procedure, the analysis of the collected thermal images, and the statistical analysis of the dataset.

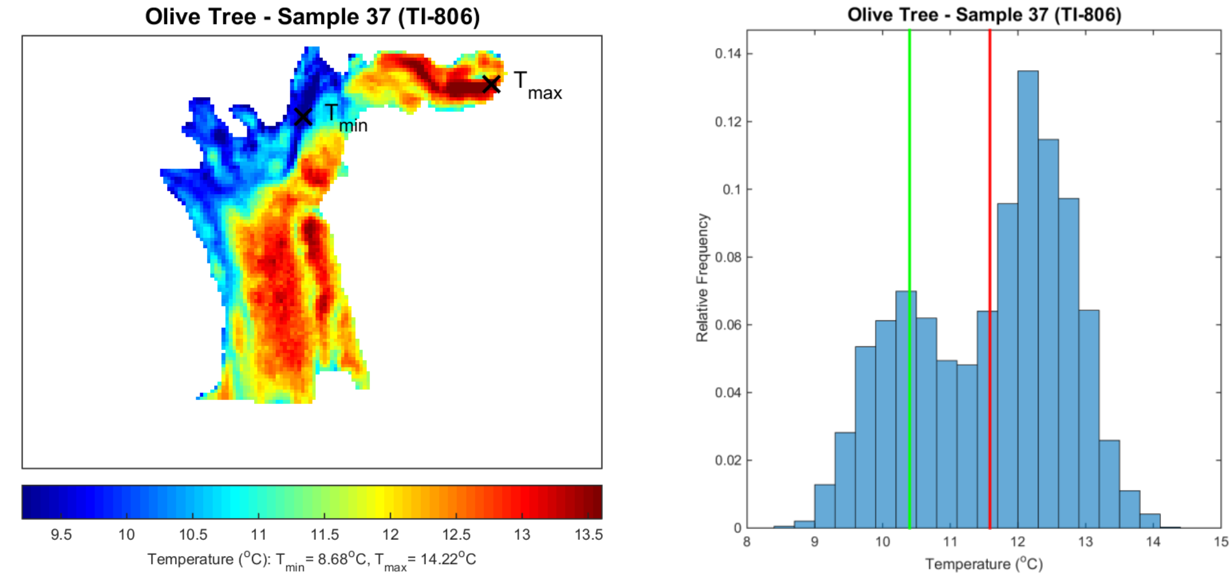

Figure 2. Sample of an individual olive tree IR image and its histogram. Temperature dissimilarities in tree trunk surface and branches describe the state of tree health. The surface temperature histogram suggests that there are two different set of sub-areas; those having mean temperature value higher than the ambient temperature (red line) and those having lower (green line) (bimodal distribution).

2.3 Data analysis

Statistical analysis was performed with SPSS software (v.20). Data were evaluated for normality and homogeneity with the Kolmogorov-Smirnov and Shapiro-Wilk tests. Non-parametric tests were used in order to identify differences (Mann-Whitney U test, Kruskal-Wallis test) and correlations (Kendall's tau-b test) between variables recorded at the two sites as well as a linear regression analysis to explain the relationship between those variables. Additionally, a hierarchical clustering was performed to identify homogenous groups of cases and Ward's hierarchical clustering method was chosen due to the fact that it is the most appropriate for quantitative variables. To avoid problems caused by different measuring scales, variables were standardized using Z-scores and a Kruskal-Wallis test was conducted to determine which classifying variables are significantly different between these cluster groups.

3. Results and Discussion

The physical dimensions of the 70 olive trees sampled for evaluation had an average diameter of 75 cm (measured at 1.3 m height) and an average height of 7.0 m. Temperatures during the IR image collection ranged between 8.8-17.0°C, relative humidity between 35-94%, and wind speed between 3.1-13.8 km/h. Comparing the thermal images of all the olive tree samples on both study areas, gave us the ability, in all cases, to detect external and reveal internal defects, consistent trends or temperature dissimilarities in tree trunk and branches surfaces (Figure 2).

Moreover, the analysis of individual trees revealed significant associations between surface temperature variations and external stem features in both sites. In particular, the number of the olive trees' cavities were positively correlated with (a) the range ($r = .442$, $n = 70$, $p < .0001$) and (b) the standard deviation ($r = .383$, $n = 70$, $p < .0001$) of the tree trunk surface temperatures. Patches of surface temperature reductions were associated with mechanical damage, detached bark, cracks and shed branch wounds.

Statistically significant differences between the two sites regarding the diameter of the tree trunks ($U = 283.5$, $Z = -3.865$, $p < .0001$, $r = -.46$), the range ($U = 429.0$, $Z = -2.156$, $p = .0310$, $r = -.25$), the mean ($U = 242.0$, $Z = -4.353$, $p < .0001$, $r = -.52$), the median ($U = 239.0$, $Z = -4.388$, $p < .0001$, $r = -.52$), and the standard deviation ($U = 435.0$, $Z = -2.085$, $p = .0370$, $r = -.24$) of the olive tree trunk surface temperature values were observed. On the contrary, there were no statistically significant differences concerning the height, the ratio of productive to total branches, the cavities and the productivity of olive trees.

Regarding the olive trees' productivity in relation with thermography (IR imaging), a statistically negative significant correlation concerning both the range of temperature values ($r = -.242$, $n = 70$, $p = .004$) as well as the standard deviation of these values ($r = -.230$, $n = 70$, $p = .006$), was observed. Moreover, a Kruskal-Wallis test was conducted to evaluate differences among the productivity of olive trees on both sites in relation with (a) height, (b) diameter, (c) ratio of productive to total branches, (c) cavities, and (d) range, mean, median and standard deviation of the tree surface temperature values. The test was significant for the (a) ratio of productive to total branches (X^2 (4) = 20.090, $p < .0001$),

(b) range (X^2 (4) = 10.797, p = .029), and (c) standard deviation (X^2 (4) = 9.673, p = .046). Follow-up Mann-Whitney U tests were conducted to evaluate pairwise differences among productivity, controlling for Type I error across tests by using the Bonferroni approach.

The results of these tests indicated a significant difference between olive trees with low and high productivity. A simple linear regression was calculated in order to predict olive trees' productivity based on the standard deviation of the tree surface temperature values. A significant regression equation was found with an R^2 of 0.132 (F (1, 68) = 11.511, $p < .001$).

Furthermore, in order to identify homogenous groups on selected characteristics of olive trees that describe the key features of the observations, hierarchical cluster analysis was carried out. The clustering was based on the comparison of the different variables that existed in the dataset, such as productivity, range and standard deviation values, and histogram distributions of each tree IR image (Figure 3). Statistically significant differences between the clusters concerning all variables, were observed. The analysis showed, in terms of thermography and productivity that three general groups (G1-G3), were detected (Figure 4):

- G1. Healthier olive trees (high productivity - low standard deviation)
- G2. Olive trees with possible structural defects (medium productivity - low standard deviation)
- G3. Olive trees with detected structural defects (low productivity - high standard deviation)

However, the relationship between thermography and productivity is differentiated between the two sites, as in Pyrgi the 2nd group and in Agiasos the 3rd group had only very few individuals (Figure 5).

Our research showed that surface temperature variations are associated with damaged or dead stem tissue, and thus the IR imaging may be useful in detecting problems of nutrition and water flow. Both healthy and under stress olive trees could be detected through thermal imaging, a technique that facilitates conservation practices concerning olive groves. Moreover, thermography is related with olive trees' productivity as the range and the standard deviation of the tree trunk surface temperature decreases, the production which is directly related to the presence or not of structural defects, increases.

Conclusions

Initial results show that olive groves could be organized in different thermal zones, based on the proposed analysis, which implies variance in their structural quality and health. The temporal variations on trees' condition, compared with environmental changes and agricultural practices could provide essential information on the resilience of olive groves. In an individual tree level, detecting and mapping various types of healthy and productive trees offers possibly significant data for specialized agricultural management. This proposed management tool supports the development of more focused and sufficient agricultural strategies for traditional cultivation of olive groves.

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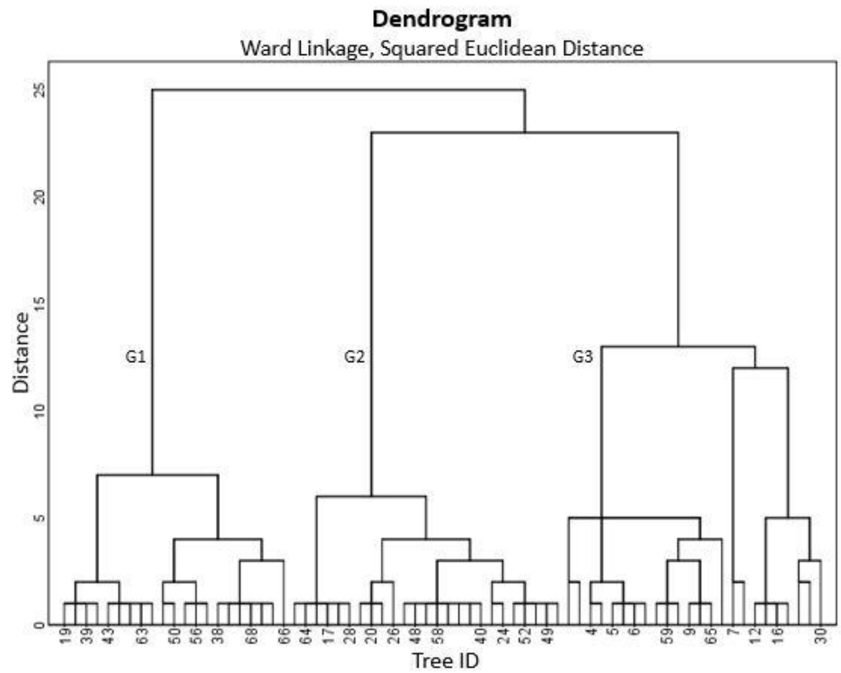

Figure 3. Dendrogram of olive trees that illustrates the dissimilarity as evaluated between Pyrgi and Agiasos sites.

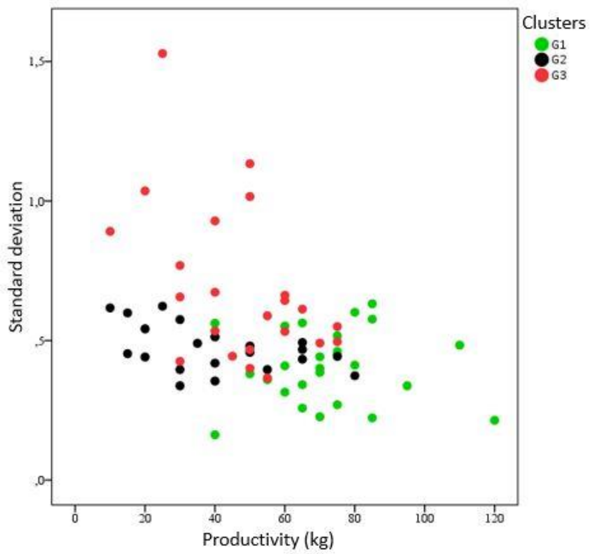

Figure 4. Scatterplot indicating the relation of standard deviation of the tree trunk surface temperature values and the olive trees' productivity based on 3 different clusters (G1, G2, G3), which were originated from the hierarchical cluster analysis.

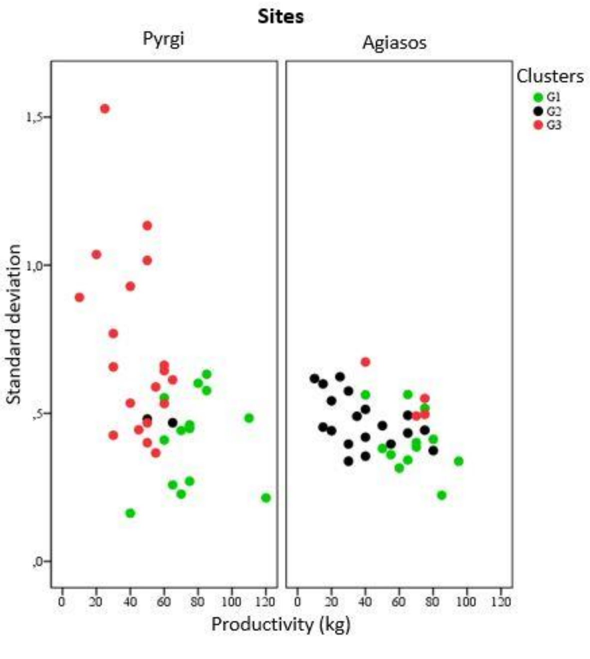

Figure 5. Scatterplot representing the relation of standard deviation of the tree trunk surface temperatures and the olive trees' productivity based on 3 different clusters in the two study areas.

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