# AN ABSTRACT OF THE THESIS OF

Tessa Angelica Barker for the degree of Master of Science in Crop Science presented on June 11, 2021.

Title: Olives in Oregon: Grower Survey, On-Farm Propagation, and Orchard Establishment in a Non-Traditional Growing Region.

Abstract approved:

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Sabry Elias

Olive production potential in Oregon was researched in a multi-disciplinary approach, including a grower survey, a propagation greenhouse study, and a field study, from 2018 through 2020. The Oregon Olive Grower Survey was designed to collect information relating to orchard establishment and management practices, knowledge and understanding of these practices, and greatest concerns and top priorities for future research from all known olive growers in the state. Survey findings show diversity in terms of farm characteristics and growing practices, while farmer concerns and research priorities were more aligned. The Oregon olive industry consists primarily of small farmers with operations ranging from less than one hectare to 5.6 ha in production, clustered in the North Willamette Valley region. Orchards contain a high number of cultivars, and growers take different approaches to crop fertility and irrigation. The most highly ranked concerns and research priorities center on cultivar evaluation for adaptability to the region in terms of winter cold tolerance, fruit set and oil yield, and anticipation of future pest problems.

The propagation study addressed the industry need for locally produced cultivars chosen specifically for production in our region. This three-part study evaluated propagation season and timing of wood collection, synthetic rooting hormone concentration and rate, cultivar rooting ability, and rooting media, for cultivars of local importance. In keeping with project goals to develop practices that

would be applicable and practical to small farmers, all propagation trials were conducted at a grower site in addition to the North Willamette Research and Extension Center. A low-input fall propagation option was evaluated at farms lacking a mist system. This study found a range of rooting hormone rates including both indole-3-butyric acid (IBA) alone and IBA in combination with naphthalene acetic acid (NAA) to be successful for spring and fall propagation, with lower root numbers, lengths, and percentages in summer. 1:1 peat:perlite media was found to be associated with better rooting, and contrary to widely accepted rankings of rooting capability, 'Picual' was easier to root than 'Leccino', which demonstrated a 75% rooting percentage when a higher rooting hormone rate was used, compared to 25% for a lower hormone rate. Results show that these cultivars may be successfully propagated on-farm in Oregon, according to specific treatments.

The field study was conducted over three years at the North Willamette Research and Extension Center (NWREC), Aurora OR and Oregon State University Woodhall III Vineyard, Monroe, OR. This trial involved a spring-planted system with raised bed and woven geotextile weed mat for weed prevention, while the fall-planted system used flat ground beds and a rotational cover crop in the aisles. Both systems evaluated vegetative evaluated strategies for rapid orchard establishment and survival in Oregon's climate, including production system approaches and overwintering and transplanting olive trees of different sizes and ages. The ultimate goal of this trial was to assess tree response to winter cold temperatures. Unfortunately, warmer weather was prevalent over the study period. growth and survival of 'Leccino', 'Frantoio', 'Amphissa', and 'Ascolano' cultivars. Comparison of spring-planting systems across both sites showed 100% survival at two years for trees planted in 2019 at NWREC vs. 68% survival for coetaneous trees at Woodhall, and greater shoot growth and trunk diameter with 'Leccino', 'Frantoio', and 'Amphissa.' At NWREC, higher shoot numbers were seen in fall-planted systems, increased shoot length in spring-plantings, similar cultivar responses, and increased survival at year two for spring-planted trees. Tree size and age at time of planting impacted growth and survival differently at each site, with increased growth but decreased survival in 1.5-year-old trees compared to 2.5-year-old trees at Woodhall, while shoot number and trunk diameter depended upon cultivar and size and age at NWREC. Overall, spring-planting and ‘Leccino’, ‘Frantoio’, and ‘Amphissa’ cultivars showed highest levels of growth for orchard establishment in Oregon.

Olives in Oregon: Grower Survey, On-Farm Propagation, and Orchard Establishment in a Non-Traditional Growing Region

by
Tessa Angelica Barker

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Tessa Angelica Barker, Author

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# CONTRIBUTION OF AUTHORS

Javier Fernandez-Salvador assisted with survey design and writing of Chapter 1.

Heather Stoven and Javier Fernandez-Salvador designed the propagation experiments in Chapter 2. Heather Stoven collected propagation data and assisted with data interpretation and writing for Chapter 2.

Javier Fernandez-Salvador designed the up-potting experiment in Chapter 3, provided guidance on field management, and assisted with data interpretation and writing.

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## 1. Introduction

Domesticated olives (*Olea europaea* L. var. *europaea*), native to the Middle East, have been cultivated in the Mediterranean region for nearly 6,000 years (Vossen, 2007). Olive production has spread to non-native growing regions around the world, including Peru, Argentina, Chile, Uruguay, the United States, South Africa, Australia, New Zealand, and China (Torres et al., 2017). Olives are long-lived, evergreen shrubs that produce an edible fruit, botanically a drupe, which can be brined and consumed whole or pressed for oil (Orlandi et al., 2003). Olive oil has held an important role in traditional diets, and continues to gain in popularity, with worldwide consumption reaching 3 million metric tons in 2018 (International Olive Council, 2019).

The spread of olive cultivation throughout the Mediterranean was marked by low-density production styles, containing low-yielding trees that could reach 50-100 years old, of regionally adapted cultivars (Tous, 2011; Vossen, 2007). This traditional production style was first introduced to the United States in California to produce brined table olives, while the recent import of the high- and super-high-density styles, first pioneered in Spain, to California have focused exclusively on oil production (Vossen and Devarenne, 2004). Compared to the traditional style, high- and super-high-density production is higher yielding and involves more intensive management including mechanization (Tous, 2011).

New olive production regions have typically had equally temperate or warmer climates than their native region (Torres, 2017). In most new production areas, farmers have adopted the high- or super-high-density production styles (Tous, 2011; Vossen and Ravetti, 2019).  These systems primarily use three lower vigor cultivars, which begin fruiting early and direct more resources towards reproductive activity than excessive vegetative growth (Farinelli and Tombesi, 2015). This has not been the production style adopted by most Oregon growers (see Chapter 2). Oregon's cooler climate and shorter growing season naturally reduces the vigor and rate of olive growth and maturation, and the small size of the industry, without easy access to mechanized pruning or harvest equipment, requires a different approach.

Introducing a crop in its nontraditional growing region, and developing an industry supporting its production involves a focus on the crop at all stages of the life cycle, and consideration of factors not usually explored in the native production area (Torres, 2017). While many Oregon olive growers have been able to establish orchards that have now reached productive maturity (see Chapter 2), research on a crop new to the area must start at the beginning, by evaluating the feasibility of orchard establishment and related factors, such as the production of planting stock, cultivar adaptability and performance in the new region, and development of production system best practices.

The overall objectives of this thesis were to collect information on the newly developed Oregon olive industry both to aid growers and researchers in designing future studies, and to explore topics related to creation of planting stock via propagation and the initial establishment of orchards in the region.

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## 2. Survey of Oregon Olive Growers Shows Diversity of Practices, Winter Cold Damage, and Need for Research to Support Production

**Abstract**

Olives are a small but expanding non-traditional agricultural industry in Oregon. Current crop statistics do not capture the full extent of the Oregon olive industry, as at the time of this survey, the majority of olive operations in the state were 5 ha or smaller in size. Growers in this state have had to rely on crop production guidelines developed for warmer regions and have experimented with cultivar choice and farming methods. In 2018, all known commercial olive growers in the state were invited to participate in an in-person, on-site survey, to collect more detailed information on current production practices and identify challenges and research priorities. Twelve growers participated, representing five counties in Western Oregon, and a total of 19 ha of olives. Site characteristics and production practices varied, with most growers producing on sloped plantings and a low density of 170 trees/ha most often reported. Sixty-six percent of respondents used fertilizer, and 82% irrigated their crop past establishment. Total state oil production ranged from 466 to 522 L in 2016 and 2017 respectively, with olives and oil sold through a variety of smaller outlets, direct to processors or consumers. Producers grew a total of 39 cultivars, with 'Arbequina,' 'Leccino,' and 'Frantoio' cited by the largest number of growers. Most farmers planted their trees directly at the age and size as received from the nursery, with a quarter of all respondents losing 75-100% of their trees due to winter cold damage over the lifespan of the orchard. Production challenges mirrored research priorities, with the highest number of growers citing cultivar selection for the Oregon climate, fruit set, and future pest management as the most important topics. Survey results show that at this point in the development of the industry, growers were focused on meeting both current and future challenges.

**Introduction**

The United States (US) ranked twentieth in world olive oil production for the 2017-2018 crop year, producing 16 thousand metric tons of oil (International Olive Council, 2019). In those years, the US produced less oil than both traditional

Mediterranean and Middle Eastern growing regions, and new olive industries in Argentina, Chile, and Australia (International Olive Council, 2019). Globally, olive production systems range from traditional low density dryland orchards to high and super high-density orchards in historical regions, and higher density systems outside the Mediterranean and Middle East (Tous, 2011; Vossen and Ravetti, 2019). The most recent census by the US Department of Agriculture (2017) found that California has the largest bearing olive hectarage in the nation (16 thousand ha), followed by Texas (239 ha), Georgia (31 ha), and Oregon, with five bearing hectares according to the National Agricultural Statistics Service (NASS) (USDA, 2019). California, with its modern high and super high-density orchards (Vossen and Devarenne, 2004), remains the only state with extensive commercial-level orchards and yields, with research trials underway as recently as 2011 in Florida (Andersen, 2015) and Hawaii (Miyasaka and Hamasaki, 2016) focused on adapting olive production to these states. No oil yield or value of production data was available from NASS at the state level for 2017.

Agricultural industries in Oregon are diverse, with specialty horticultural crops, row crops, meat, dairy, and seafood among the top twenty commodities in 2018 (Losh 2019). Tree fruit such as pears, cherries, and apples ranked as the 10th, 16th, and 18th top commodities, respectively (Losh, 2019). Olives, grown for both oil and brined table olives, make up a small fraction of production, with five bearing hectares included in the last census, out of a total of 6.5 million farmed hectares in the state (Losh, 2019; USDA, 2019). Olives represent an opportunity for Oregon farms to diversify production with a new-to-the-state value-added product. Despite the production volume being small, growers are able to produce a high-quality oil, with prices ranging from $50-140 per gallon (3.8L) (Durant, 2021; River Ranch Olive Oil 2021), and some have received international awards (NYIOOC, 2020).

Farmers in Oregon previously obtained crop production information from University of California Cooperative Extension services. While valuable, this is guidance based on the more developed industry and higher density planting system in California, which is not wholly applicable to this state. The Oregon olive industry began two decades ago, with roughly ten growers and one commercial mill. Since then, new and existing olive growers have experimented with multiple cultivars and production practices. The most striking difference between these two regions is climate. California's major olive growing regions include the North, Central, and South Coasts, the Sacramento and San Joaquin Valleys, and the Sierra Foothills (Vossen and Devarenne, 2004), the majority of which are in USDA plant hardiness zones 9a or 9b, with average annual extreme minimum temperatures of -6.7 to -1.1 °C (USDA, 2020). In contrast, Oregon's main olive production areas are in zones 8a through 9a, with corresponding average annual extreme temperatures of -12 to -4 °C (USDA, 2020).

Olives are native to the Middle East and having historically been grown in Mediterranean regions are not well-adapted to growing in colder climates (Vossen, 2007). Small limbs may be damaged or fatally wounded at -6 °C with larger limbs or whole trees damaged or killed below -9 °C (Sibbett and Osgood, 2015). Limited field studies on winter cold injury show that specific cultivar tolerance to this damage varies (Gómez-del Campo and Barranco, 2005). Due to differing climates, the prospect of winter cold damage is more likely in Oregon, though it is not unheard of in other, warmer olive growing regions. A case study of a two-week freeze event in the California Sacramento and San Joaquin Valleys in 1990 documented the damage to olive trees, ranging from tip burn to limb dieback (Denney et al., 1993). More research is needed on the effects of the Oregon climate on potential cold damage to the cultivars grown here.

With the expansion of the Oregon olive industry, there is an increasing need for best practice research on olive production in the state. The Oregon State University (OSU) Olea Project was formed in 2017 to conduct this field research. More detailed statistics on the Oregon olive industry are also needed to guide research and inform marketing strategies. Surveys and case studies have been used to learn about olive growers and industry members from the Mediterranean and Middle East to western Australia and California in the US (Alonso and Northcote, 2010; Apaydin, et al., 2014; Areal and Riesgo, 2014; Vossen and Devarenne, 2004). These studies show vast contrasts between the regions represented, including differences in industry age and developmental level, government support for the crop, and links between olive production and local culture. The objectives of this survey were 1) to identify research needs of Oregon olive growers, to inform research projects and Extension programming and outreach, and 2) to collect more comprehensive and complete data on the Oregon olive industry.

**Materials and Methods**

*Participant selection.* On-site, in-person interviews were used as the method to collect both qualitative and quantitative data. Due to the small size and young age of the industry, all known growers were invited to participate, with the goal to interview each member of the grower community as in a census, rather than a representative sample. Survey participants were selected from advice and contacts given by growers in OSU Olea Project Advisory Council, an informal grower council that provides guidance on OSU olive research, with additional respondents identified from a list of olive producers maintained by the research team and OSU Extension's Mid-Willamette Valley Small Farms Program. Initial invitations to participate were sent via email and follow up communication conducted over the phone.

*Interview process.* Surveys were conducted by one interviewer (Barker) to ensure consistency. Most interviews were held at grower sites Nov. 2018 through March 2019. Survey responses were anonymized. An online version was created, but data collected was incomplete and not usable.

*Survey design.* Survey questions were grouped into four categories (see Appendix A). The first consisted of five questions focused on respondent contact information (in case of follow up/clarifying questions; later redacted) and farm characteristics including farm location. The second pertained to production practices and included one question on total planted and olive planted area, one question on site characteristics, three questions on propagation, one on tree spacing, three on fertilization and irrigation, two on organic certification, and eight questions on marketing and yields. The third category addressed issues linked to risk of winter cold damage, with two questions on cultivars grown, two on orchard establishment methods, and one question on winter damage sustained over the lifespan of the orchard. The fourth category asked growers to 1) rank their knowledge and understanding of current OSU Olea Project topics, 2) cite the production challenges they face, and 3) identify priorities for future research. Questions asking respondents to rank their knowledge of OSU Olea Project research topics identified these as focused on “best practices for olive propagation in Oregon”, “up-potting/transplanting and overwintering practices for olives”, and “olive cultivars best adapted to Oregon”, as these were the topics recommended by the OSU Olea Project Advisory Council. Two open-ended questions asked participants to identify their three greatest production challenges and top three research priorities. The survey was reviewed by OSU’s Human Research Protection Program and Institutional Review Board.

*Data analysis.* Data were analyzed using Microsoft Excel (version 2102; Redmond, WA, USA) to determine measures of central tendency, frequencies, and percentages for quantitative questions. For questions addressing knowledge and understanding, means were calculated for each category. For questions regarding production challenges and research preferences, responses were coded to categories including cultivar selection and tolerance to winter cold damage, fruit set and oil yield, future pest management, economics and marketing, propagation, cost effective harvest, and “other” (included fertility, processing, pruning, table olive cultivars and sensory testing of oil), and category frequencies and percentages were calculated.

**Results and Discussion**

*Farm Characteristics: Location.* Twelve individuals participated in the in-person survey interview process (a 100% response rate of all invited growers). Respondents’ olive growing operations represented five counties within western Oregon. The highest percentage (33%) of growers were located in Yamhill County, with 25% in Polk County, 17% each in Benton and Douglas Counties, and 8% in Marion County (as shown in Fig. 2.1). This equates to two-thirds of responding farms being located in the northern and mid-Willamette valley.

This clustering of olive operations may be related to both climatic and cultural factors. Eastern Oregon has a more extreme climate than the western half of the state, falling into USDA plant hardiness zones 6a, 6b, and 7a, with average annual extreme minimum temperatures between -23 and -15 °C (USDA, 2020). Western Oregon occupies zones 8a through 9a, with corresponding minimum temperatures of -12 to -4 °C (USDA, 2020). Because olives can begin to experience damage at -6 °C, with larger limbs and whole trees susceptible to damage or death at colder temperatures (Sibbett and Osgood, 2015), it is impractical to grow olives in eastern Oregon.

In addition to climate, social factors may impact olive oil industry development in the north and mid-Willamette Valley. Many growers in this region are personally acquainted and reported providing production assistance to each other. Responses to survey questions on olive tree sourcing indicated that producers purchased plants directly from other local growers as well as collaborating on bulk nursery orders. Seventy percent of respondents continue to work together, contracting milling or directly selling fruit to the Oregon Olive Mill. The close proximity of these farms and support received from established operations may have created a local culture in which entry to the industry is easier for new growers. This in turn may have led to an increased number of orchards in this area over the past decade. Continued relationships between Oregon olive farmers may be compared to the "neighbor effects" described by Areal and Riesgo's 2010 survey of Andalusian olive producers, which they define as "occur[ing] when [a] farmer's view on olive production in future may be influenced by that of the neighbor farmer" (2014).

*Production Practices: Area Planted, Tree Spacing, Fertility, Irrigation, Yields and Marketing.* Respondents held a total of almost 500 farmed hectares, with 19 ha planted to olives. One producer had not yet planted their orchard but was currently managing potted trees in a greenhouse. Responses are not reported for this interviewee when not applicable (i.e., planting density and yields), and for those results, percentage results only pertain to individuals with applicable answers for established orchards.

Planted olive area per site ranged from less than one hectare to 5.6 ha, including bearing and non-bearing hectarage (as shown in Fig. 2.2). The majority of plantings (82%) were on hillside or sloped terrain, with the remaining 18% evenly split between valley floor or flat ground and combination land containing both sloped and flat areas. Half of the respondents had soil classified as silty clay loam, 25% had silt loam, and the remaining 25% had mixed and other soil types. Row spacing varied, with some plantings having as few as 1.5 m between rows or 1.2 m between trees. The most common spacing was 3 m x 3 m, equivalent to 170 trees/ha. Oregon olive production system planting density falls between what Tous identifies as “traditional” (fewer than 120 trees/ha) and the lower end of “intensive” (200-450 trees/ha) (2011). “Traditional” refers to areas where olives were historically grown, including the Mediterranean and the Middle East. According to Tous, half of the 11 million ha of olive area in the world follow traditional production practices (2011). Regarding sloped land Oregon orchards once again have more in common with traditional plantings. These may be located on flat ground or “moderately steep” slopes (Tous, 2011).

Two-thirds of growers fertilized their olives. Eighty-two percent of respondents irrigated through the entire life of the orchard, while 18% irrigated only during establishment. This moderate level of inputs, and mixed irrigation practices is comparable once again to traditional production systems, which may be either dry farmed or use drip irrigation (Tous, 2011). In some historical regions, growers have recently begun to “modernize” and intensify operations, while in areas such Turkey, Tunisia, Syria, and Morocco, the traditional system remains (Tous, 2011; Tunalioglu, 2008). In contrast, modern higher density orchards require more technical management of soil fertility and irrigation (Tous, 2011). Vossen and Ravetti state that “irrigation is the most important factor” in obtaining higher yields. They further state that fertility programs must account for nutrients required for vegetative growth and fruit development, as well as the portion of canopy removed by pruning and nutrients removed with the fruit during harvest (Vossen and Ravetti, 2019). The finding that some Oregon growers did not irrigate or fertilize their orchards suggests they may not have been achieving their full potential yields. Yields (kg fruit and/or L oil) were available for six of the surveyed farmers for the 2016 crop year, and eight farmers for the 2017 crop year. Average fruit yield was 562 kg/ha in 2016, and 608 kg/ha in 2017. Total fruit production was 4,895 kg in 2016, and 9,996 kg in 2017. These numbers do not include that of participants who only reported their oil yield. Average oil yield (L/kg) was 0.12 L/kg in 2016, and 0.22 L/kg in 2017, with total oil production at 466 L in 2016, and 522 L in 2017. This translates to 73 L/ha oil in 2016, and 22 L/ha oil in 2017. These numbers do not include the oil yield of those operations that sold fruit directly to the mill or consumers. Oregon olive fruit and oil yields were substantially lower those in other production regions, which can range from one thousand kg/ha fruit to 12 thousand kg/ha fruit, depending on planting density and crop management intensity (Tous, 2011).

Responses indicated a range of market outlets for Oregon-grown olives and oil. These included selling fresh fruit directly to processors (cited by 2 out of 10 growers with bearing acreage), direct farm sales (3 out of 10), and farmers markets (4 out of 10). Two respondents reported not selling their oil, and instead keeping for personal use, gifts, or marketing purposes. None claimed to sell fruit or oil through large chain stores or via wholesale. This focus on direct-to-consumer marketing, whether through on-farm sales, farmers markets, or as promotional gifts, aligns with marketing strategies for small farms described by Stephenson and Lev in their 2004 study of support for local farms in Oregon. Additionally, these are venues where locally grown products are often highlighted (Stephenson and Lev, 2004), which fits the profile for Oregon olive oil as a niche market product. The majority of respondents' farms are not certified organic, nor are they interested in certification.

Surveyed growers produced olives primarily for oil. Two respondents produced table olives non-commercially, and two-thirds were interested in commercial production of table olives in addition to oil. This higher percentage producing oil compared to table olives may be due to cultivar choice and growing season constraints. Compared to California, the shorter, cooler growing season in Oregon results in olives that may not reach full maturity or large fruit size (Vossen and Ravetti, 2019). Some Tuscan cultivars grown by respondents, including 'Frantoio,' are harvested at an earlier green stage in both their region of origin and beyond (Vossen, 2007). Earlier-harvested, less mature fruit may be smaller and have a "grassy" flavor, which is suitable for oil, but less desirable for table olives which are typically larger (Vossen, 2007).

*Winter Cold Damage: Cultivars, Orchard Establishment Methods, Damage Sustained.* Both cultivar choice and orchard establishment method, in terms of tree age and size at time of planting, are linked to the risk of winter cold damage in the Oregon climate. Cultivars show a range of susceptibility towards this damage. Meanwhile, growers in the state have provided anecdotal evidence of establishment method impacting the amount of damage their orchards receive. Respondents grew a diversity of cultivars, totaling 39 after removing synonymous names (Fig. 2.3). The majority of these (30 cultivars) were grown at three or fewer operations, with an average of eight cultivars per farm. This contrasts with the super high-density olive production system exemplified by California that focuses on the three cultivars 'Arbequina', 'Arbosana', and 'Koroneiki' with precocious qualities well-suited to that system (Vossen, 2007). The high number of cultivars grown in Oregon was likely linked to there being no single cultivar or group of cultivars yet identified as best adapted to the climate in this state. While growers have experimented on their own land for two decades, prior to the OSU Olea Project there have been no replicated, peer-reviewed cultivar evaluations.

The most widely crown cultivars indicated by respondents were 'Arbequina,' 'Leccino,' 'Frantoio,' 'Pendolino,' 'Aglandau'/'Nichitskaia,' 'Arbosana'/'Bosana,' 'Nevadillo'/'Picual,' and 'Piccolino'/'Picholene'. According to surveyed growers, California nurseries originally recommended 'Arbequina' as most suitable for the Oregon climate when orchards in this state were first being established. Vossen lists 'Arbequina' as "hardy" in his 2007 short history of olive oil. In contrast, a 2016 field study in central Italy demonstrated high susceptibility to frost damage in this cultivar (Lodolini et al.), which aligns more with Oregon growers' experiences. It is important to note that studies conducted in warmer regions may refer to cultivars as being cold hardy or cold tolerant, though this does not necessarily translate to these cultivars being tolerant of cold damage in a climate such as Oregon. Survey results indicate producers shifted from a singular focus on 'Arbequina' towards planting a diversity of cultivars, including the Tuscan 'Leccino', 'Frantoio,' and 'Pendolino'. Tuscan cultivars have the potential to thrive in the climate in this state, as Tuscany experiences cold winters, with frosts common after the middle of December (Vossen, 2007). 'Leccino' is considered by multiple sources to be "cold hardy" (D'Angeli, Malhó, and Altamura, 2003; Vossen, 2007), 'Pendolino' is considered "hardy" (Vossen, 2007), and depending on the source, 'Frantoio' is "semi-hardy" (D'Angeli et al., 2003) or "sensitive" (Vossen, 2007).

Eighty-three percent of respondents purchased trees from a total of six California nurseries, while 17% purchased trees from Oregon, including one nursery. Over half of those surveyed also purchased California trees re-sold by other local growers, and/or went in on wholesale purchases with others. The small number of olive nurseries in the state compared to those in California reflects differences between industry size and development in these states (Vossen and Devarenne, 2004). Oregon olive producers have fewer options for sourcing trees in-state, with no wholesale nursery operating at the time of the survey, which may explain why some chose to buy trees directly from other growers, rather than from out of state.

Limited options for purchasing trees in-state demonstrates the importance of on-farm propagation, which provides growers with additional options for increasing their number of trees. It also gives greater flexibility in choosing cultivars with potential tolerance to winter cold damage, while avoiding the cost of shipping trees from out of state and the risk of importing pests from California (Zalom et al., 2009). Responses indicate that only one-third of Oregon olive producers propagated their own plants, despite nearly two-thirds having greenhouse facilities. There was no trend in propagation seasonality: one grower propagates all year round, one in summer, one in fall, and one in winter or spring. The fact that growers here exhibited a limited amount of on-farm propagation, and did not demonstrate specific seasonal pattern in their propagation activity is likely due to the lack of research on olive propagation in Oregon, prior to the OSU Olea Project. This survey was conducted prior to completion of the propagation study, and so growers did not yet have access to results though they were aware research was in progress.

Some respondents described overwintering and “up-potting” or transplanting to larger pots, to grow trees to a larger size before planting and reduce or avoid winter cold damage that can be deadly to smaller trees. Growers demonstrated varied establishment practices, with 42% planting some or all of their trees after overwintering and up-potting, and 67% planting some or all of their orchards directly, using the trees at the age/size purchased. Percentages add up to greater than 100% due to some using both methods. The majority of growers who overwintered plants reported up-potting young trees into 2.8 L pots and growing for at least one year before planting. Only one respondent reported using larger 15.8-19 L pots. While some growers had success with overwintering and/or using larger, older trees to avoid cold damage, the lack of standard practices plus additional costs associated with overwintering and up-potting (this can include greenhouse infrastructure, energy costs for backup heating, potting media, pots, and labor) may have prevented more growers from engaging in this practice. Respondents demonstrated uniformity in selecting a planting season, with 100% planting in the spring. This is in line with California standards, which encourage spring planting to avoid winter cold damage to newly planted trees (Vossen and Ravetti, 2019).

Surveyed growers reported a range of experiences with winter cold damage. Over one third of respondents lost between 0% and 25% of the total number of trees planted, an equal amount lost between 75% and 100%, and a quarter lost between 50% and 75% of trees planted over the lifespan of the orchard (Fig. 2.4). These varied responses may be due to differences in planting region within Oregon and orchard microclimates, cultivar, and planting year. At the county level, respondents located in Douglas County in southern Oregon were among those reporting extreme losses of 75% or greater, with no producers from that county reporting losses below 25%. Compared to other counties represented in this survey, Douglas County tends to have more extreme winter weather, with growers reporting first frosts occurring earlier in the season than in more northern counties. Cultivar choice could also impact winter cold damage rates. The four respondents reporting losses of 75% or greater grew a total of 19 different cultivars, while those reporting 25% of fewer losses grew over 30 different cultivars, suggesting that increased diversity may protect against greater losses. Regarding planting year, two producers reported losing their entire orchard due to winter cold damage in 2013, during which there were record low temperatures in the Willamette Valley (Dello, 2013).

*Production Challenges, Knowledge and Understanding, Research Preferences.* Growers rated their knowledge of “olive cultivars best adapted to Oregon’s climate” higher than other topics, with an average of 2 out of 3. They rated knowledge of “best practices for olive propagation in Oregon’s climate” at a 1 out of 3. Average knowledge of overwintering and up-potting practices for olives was rated at a 1.7 out of 3. These ratings point to differing levels of understanding based on the topic. It was understandable growers would report a low level of knowledge for propagation at this stage, as the Olea Project propagation study was still underway in 2018-2019, with full results and outreach materials not yet published. The higher ranking for knowledge of cultivars may be linked to more established growers' experience and learning through trial and error. The intermediate ranking for overwintering and up-potting may correlate with the fact that few have attempted these techniques though many have been exposed to the concept and witnessed demonstrations through Olea Project field days and presentations.

Over 20% of responses to the question of production issues were related to winter cold damage (as shown in Fig. 2.5), which was also the top stated research priority (as shown in Fig. 2.6). The topic of winter cold damage and cultivar selection for cold tolerance points to the main limiting factor for olive production in the state. The risk of tree damage or death from winter cold damage is the greatest threat to growing olives in Oregon. Despite survey respondents ranking their knowledge of cultivars best adapted to Oregon's climate at a 2 out of 3, growers are clearly still very interested in scientific research on cultivars that are more tolerant of cold temperatures.

Concern over cultivar selection is linked to fruit set, another top production issue and research priority (as shown in Figs. 2.5 and 2.6). Cultivars better adapted to the Oregon climate should be less susceptible to winter cold damage, allowing the trees to reach reproductive maturity sooner than those that have suffered successive cycles of damage and dieback. Alternatively, cultivars that may be less adapted to winter low temperatures could show delayed development if some portion or all of the tree is damaged. Olives produce fruit on previous season growth (Vossen and Ravetti, 2019), which is also the wood that is most susceptible to cold damage (Sibbett and Osgood, 2015). Trees that experience winter cold damage in one year will likely have fewer fruiting sites and lower yields the following year. Assessing the climate in Oregon as a whole, in addition to research on cold tolerance of cultivars, research may also be needed on the impact of precipitation on fruit set, as olives are wind pollinated, and tend to bloom in mid-June in this state, when rain may interrupt pollination.

Fruit set is also impacted by overall orchard management, which places Oregon growers at a disadvantage as best practices for olive production in the state are still in development. Producers have had to experiment to determine fertilizer and irrigation timing and rates, and training and pruning strategies to encourage fruiting. This is reflected in survey responses showing a variety of growing practices, including fewer than 100% of growers fertilizing and irrigating their olives at the levels suggested for commercial production in other regions.

Finally, respondents cited pest and disease management as an issue of future concern, as well as a priority for future research (as shown in Figs. 2.5 and 2.6). As a newer crop in Oregon, olives have few insect pests, none of which are at destructive levels. This may change as the industry grows, and more area is planted to olives. Diseases and pests that present a major concern in other regions, such as *Xylella fastidiosa*, a bacterium responsible for olive quick-decline syndrome, and olive fruit fly (*Bactrocera oleae*), are absent from Oregon (Abbott, 2018; Zalom et al., 2009). Pests that have been encountered include twig and branch borer (*Melalgus confertus*, see Appendix B), black scale (*Saissetia oleae*, see Appendix C), and leafroller (Lepidoptera: Tortricidae, see Appendix D) larvae, with diagnostics provided by OSU Plant Clinic. It is currently unknown whether these pests will behave similarly as in other regions, or if they may be partially controlled by winter low temperatures. Many growers have also cited issues with vertebrate pests, including rodents, rabbits, and deer, with future studies needed to determine the extent of these pests and evaluate control measures if necessary.

**Conclusion**

Faced with the challenge of establishing a commercial crop in its non-native climate, surveyed Oregon olive growers demonstrated a wide range of production methods. The most common practices included planting trees directly as received from the nursery, establishing fields in spring, and using fertilizer and irrigation throughout the life of the orchard, though these methods are not universal. In contrast, there were farmers who did not plant directly but instead overwintered and up-potted their trees, transplanting them to the field at older ages. Additionally, some did not use fertilizer, and some only irrigated at establishment. As of 2017, growers produced an average of 608 k/ha fruit, resulting in oil yields of 0.22 L/kg, or 22 L/ha. These numbers are extremely low compared to yields from other production regions (Tous, 2011; Vossen and Ravetti, 2019), reflecting the young age of this industry, and the lack of standardized production methods designed to increase yields.

Producers have experimented with a large number of cultivars, but due to a range of experiences with winter cold damage, they still identified cultivar research as a top concern and a priority. Growers additionally identified the current challenge of achieving high fruit set and yield, and the future challenge of pest management as research priorities. Low yields may be related to production practices, cultivar choice, and the challenges of the Oregon climate and persistent winter cold damage to trees. Research is needed to identify both the production practices and cultivars that are best suited to Oregon, in order to increase fruit set and yields.

Growers' concern over future pest and disease management demonstrated that they were looking ahead and were committed to anticipating and preventing challenges to their olive growing operations over the long term. This concern also demonstrated that there is still much that is not known about olive production in Oregon. As the industry develops, with more growers establishing new orchards and existing farms expanding their operations, research will need to keep pace with the challenges facing these producers, and Extension and outreach efforts will be needed to ensure participants at all stages have access to the best information available.

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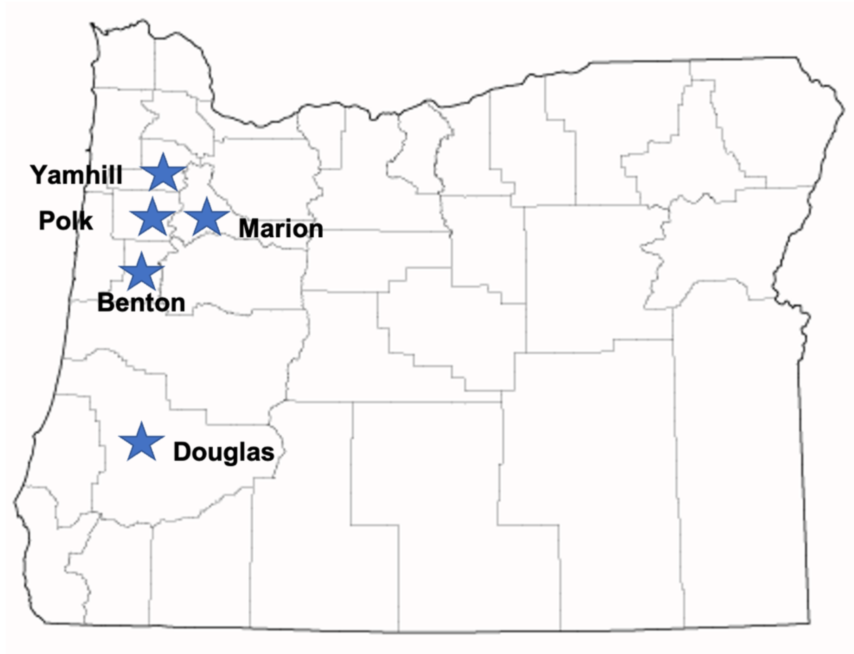


Fig. 2.1. Counties in Oregon where olives are grown as of 2018-2019 (n = 12). Data obtained from in-person survey. Map image from USDA, 2021. (https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=OREGON)

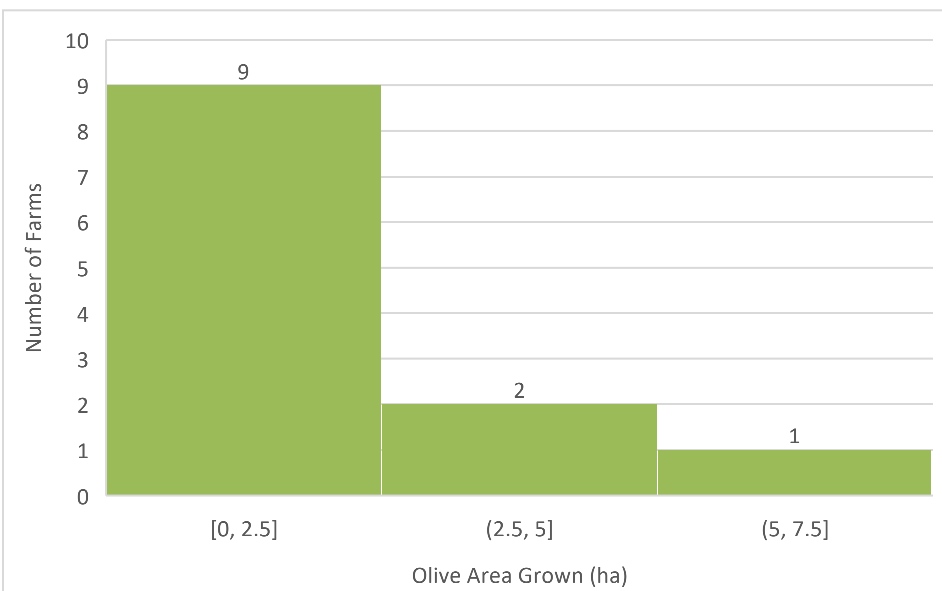


Fig. 2.2. Number of growers with 0-2.5 ha, 2.5-5 ha, and 5-7.5 ha of olives, respectively, as of 2018-2019 (n = 12). Data obtained from in-person survey.

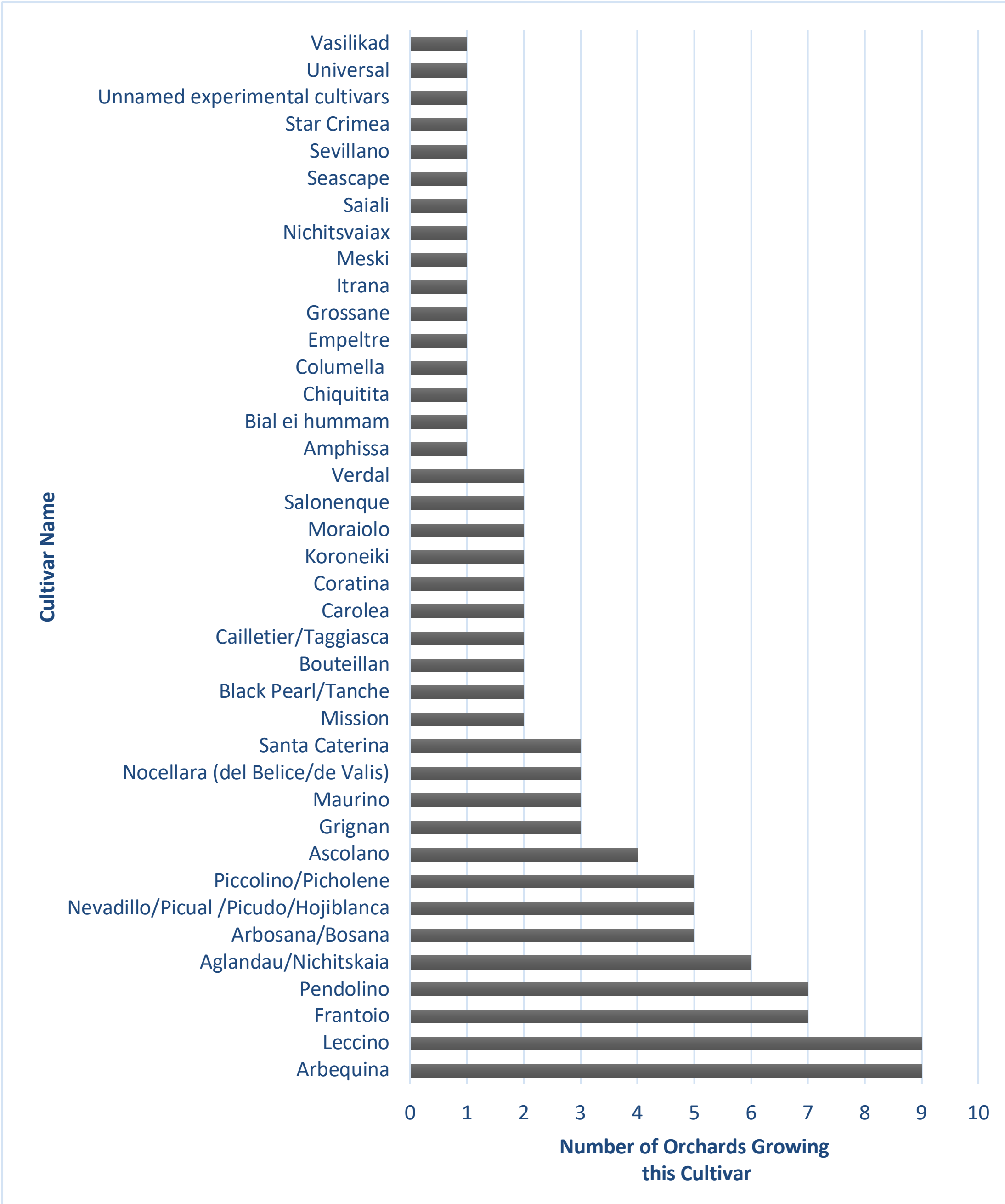


Fig. 2.3. Number of Oregon olive orchards growing specific cultivars as of 2018-2019 (n = 12). Data obtained from in-person survey.

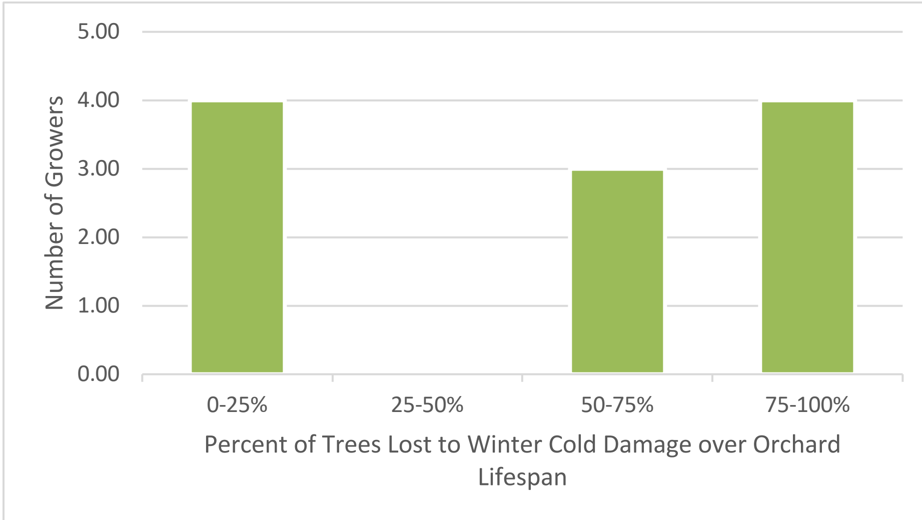


Fig. 2.4. Number of Oregon olive orchards that lost trees to winter cold damage over the lifespan of the orchard, 2018-2019 (n = 12). Data obtained from in-person survey.

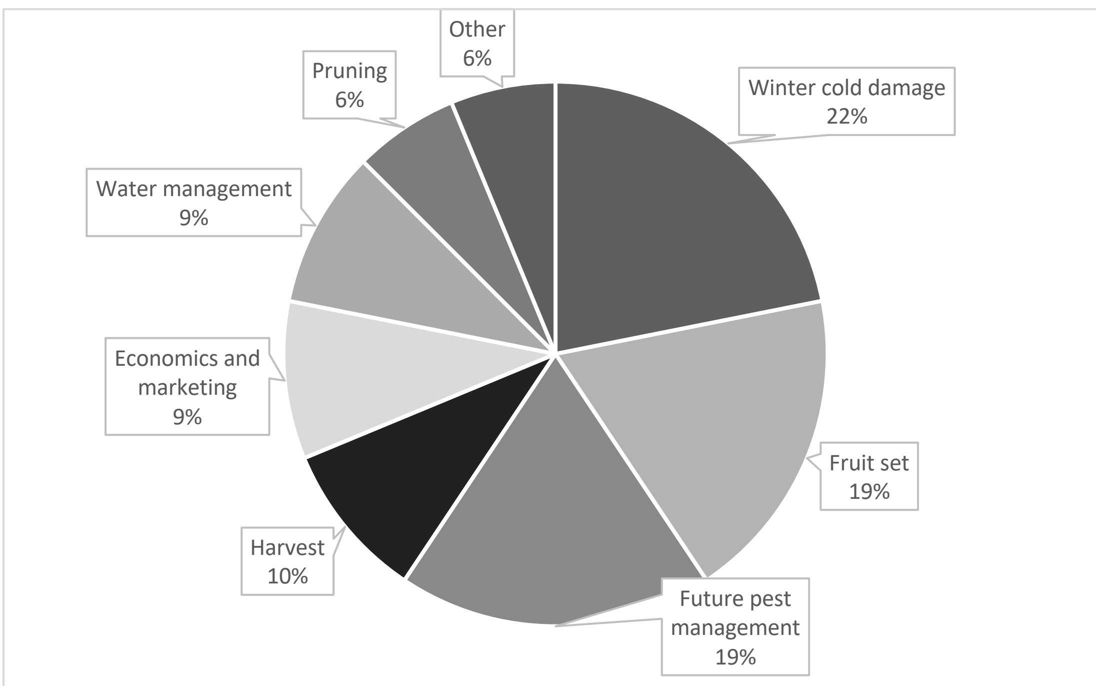


Fig. 2.5. Proportion of Oregon olive growers citing specific production issues according to eight categories as of 2018-2019 (n = 12). Data obtained from in-person survey.

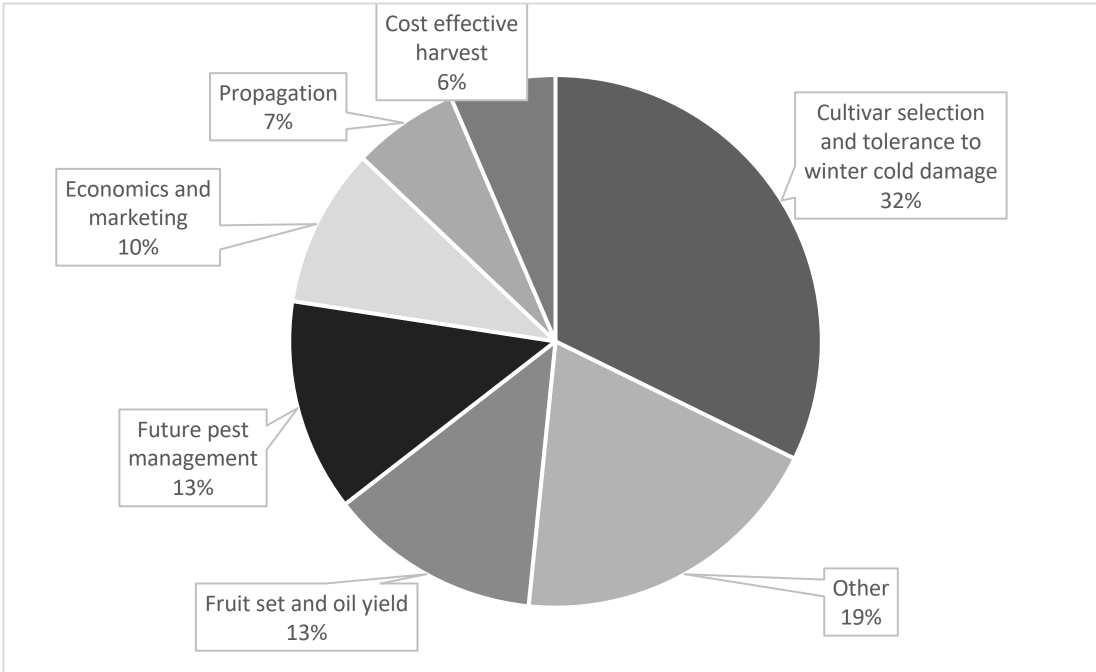


Fig. 2.6. Proportion of Oregon olive growers citing specific research priorities according to seven categories as of 2018-2019 (n = 12). Data obtained from in-person survey.

# 3. On-Farm Olive Propagation in Oregon

## 3.1: 'Arbequina' Rooting Success Varies Based on Rooting Hormone and Seasonality

**Abstract**

The most common method for propagating olive trees is rooting semi-hardwood cuttings. Regionally specific best practices are needed for on-farm olive propagation in Oregon in the Pacific Northwest of the United States, where the climate is cooler than many other olive production regions and olives have a delayed developmental cycle. This first in a two-part study was conducted to determine the optimal rooting hormone combination and concentration and season for propagating an easy-to-root cultivar in the climate in Oregon. 'Arbequina' cuttings measuring 7.5 cm long were taken from a mature orchard in Dayton, Oregon, and propagated using low and high concentrations of indole-3-butyric acid (IBA) alone (referred to as 3H and 8H) and in combination with naphthalene acetic acid (NAA; referred to as 2D and 4D) for rooting in 1 peat : 1 perlite (by volume) media. The experiment was conducted in spring, summer, and fall of 2018 and 2019, Aurora and Dayton production sites in Oregon. Greater rooting percentages occurred in spring (78%) and summer (74%) in Aurora compared to Dayton, and during Spring 2018 and Fall 2018 averaged across both sites, with 71 and 74% rooting, respectively. The impact of rooting hormone varied based on season. The 2D, 3H and 8H treatments led to greater root number, length, and percentage in spring. In summer, 3H led to greater root number and length, and both 3H and 2D produced high rooting percentage. All four hormone treatments produced high root number and percentage, but low root length in fall. Findings suggest that 'Arbequina' olives may be successfully propagated during each of the three evaluated seasons, with varied responses to differing hormone types and rates.

**Introduction**

Rooting of semi-hardwood cuttings is the most widely used technique for olive tree propagation. (Fabbri et al., 2004). Asexual, clonal forms of reproduction are preferable to sexual reproduction, as seeds will show characteristics of both parent plants, and olive seeds may have low or delayed germination rates due to a double dormancy requirement (Fabbri et al., 2004). Grafting as way to increase tree numbers has benefits for mature orchards including changing cultivars or repairing damaged trees (Fabbri et al., 2004). Grafting would not however be appropriate for olive production in Oregon, due to the demand for plants for establishing new orchards. The increased risk of winter cold injury in Oregon may also put grafted trees at a disadvantage, as grafted scion wood could be damaged, leaving only the rootstock intact (Sibbett and Osgood, 2015). Vegetative propagation has the benefit of producing large numbers of genetically similar plants. When conducted on-site or in the same region as olive production sites, this technique may also avoid the import of foreign pests that can occur when bringing in large quantities of plants from out of state. Micropropagation or tissue culture is another option for producing clonal plants, though this technique requires laboratory access and familiarity with multi-step procedures (Fabbri et al., 2004). This study will evaluate procedures for vegetative propagation of cuttings, which may be done more easily in a greenhouse.

Propagation success is based on the ability of the plant to produce adventitious roots (Fabbri et al., 2004; Porfírio et al., 2016). These roots are derived from dedifferentiated cells, induced by the mechanical wounding of the plant tissue, rather than being pre-formed roots (Fabbri et al., 2004; Porfírio et al., 2016). Rooting success is influenced by factors including the rooting hormone type, concentration, and combination; seasonality of the propagation process and its link to wood age; and rooting media used (Porfírio et al., 2016). Olive cultivars demonstrate a range of rooting abilities (Fabbri et al., 2004), which are not currently known to be linked to any anatomical differences between the cultivars with differing rooting capacity (Porfírio et al., 2016).

Porfírio et al.’s 2016 review of current research on adventitious root formation in olive found that numerous studies have been conducted on the effect of synthetic auxin or rooting hormone concentration, stating that indole-3-butyric acid (IBA) is most used, and often leads to the best results. 1-naphthaleneacetic acid (NAA) is also widely used, in addition to combinations of IBA and NAA (Porfirio et al., 2016). Fabbri et al. clarify that NAA alone or in combination with IBA is typically used for cultivars that show decreased success with IBA (2004). In studies where rooting hormone was not a treatment, the most used hormone was IBA at a concentration of 2000-4000ppm (Ahmed et al., 2002; Awan et al., 2003 and 2012; Denaxa, Vemmos, and Roussos, 2012; Fouad, Fayek, and Selim, 1990; Isfendiyaroglu, Özeker, and Baser, 2009; Yilmaz, Mahmutoglu, and Ozkok, 2019). Studies where rooting hormone was a treatment typically examine a wider range, from 1000ppm to 6000ppm IBA, with varied results. Ismaili and Lani found a positive correlation between an increased IBA concentration and root number (2013), while Khajehpour, Jam, and Khajehpour showed increased roots numbers with 3000ppm IBA, but greater root length with 4000pp IBA (2014), which is comparable to Khattak et al. (2001) and Kurd et al. (2010)'s findings of longer roots at 4000ppm IBA. In contrast, Talaie and Zohouri found the greatest root length with 3000ppm IGA, and greatest root number with either 3000 or 4000ppm IBA (2019). Denaxa et al. also examined the use of NAA alone and in combination with IBA, demonstrating higher rooting percentages with 'Arbequina' and a lower IBA rate in summer, and a combination of NAA and IBA in the fall (2011).

Compared to the number of studies on rooting hormone concentration, there have been fewer studies on the effect of propagation season on rooting success. Fabbri et al. indicate that the best times to propagate olives in central Italy are April and September-October, which correspond with peak levels of endogenous rooting hormone levels within the plant (2004). Porfírio et al. note a trend in the literature for higher rooting percentages in summer, with lowest percentages in autumn and winter, but later state that spring and fall are the best seasons overall for semi-hardwood cuttings (2016). They draw a connection between seasonality of propagation and carbohydrate status of stock plants over the year as well as the juvenility of cuttings, with cuttings taken from more physiologically mature parts of the plant showing greater rooting success in spring and summer (Porfírio et al., 2016). Local climate may play a role in choosing the optimal season, and can change the methods used for propagation. Our study included a complimentary trial in the fall utilizing periodic watering and a plastic tray cover, instead of a standard misting system, to both take advantage of the cooler, wetter conditions present in the Oregon climate in the fall, and provide growers with a lower-input option. As far as we are aware, no other studies have explored this technique for olive propagation.

The best season for propagation may also depend upon cultivar rooting ability. Studies of multiple hard-to-root cultivars show some having the highest rooting percent in March, while other cultivars perform best in September (Cirillo et al., 2017). There are examples of specific cultivars with optimal propagation seasons for nearly every month of the year, with 'Leccino' demonstrating a high rooting percent and number of roots in February and April respectively (Ahmed et al., 2002), Denaxa et al. showing 'Arbequina' having high rooting percentage in July (2012) and November (2011), and Khabou and Triqui's 1999 study examining seven different cultivars finding the highest rooting percentages in December and January.

While the literature presents a useful baseline, the majority of the studies referenced above were conducted in either the Mediterranean or the Middle East, regions with very different climates than that of Oregon. Olives show a delayed start to the growing season, and an overall shorter growing season in Oregon compared to warmer regions, necessitating research on best practices for olive propagation in this climate. The objective of our two-part propagation study was to determine best practices for on-farm olive propagation in Oregon's climate. The objectives of part 1 were to determine the impact of 1) propagation season and corresponding wood age and developmental stage, 2) rooting hormone concentration and combination, and 3) propagation irrigation method in fall only, on rooting success of a widely grown, easy-to-root olive cultivar.

**Materials and methods**

*Plant material.* On 25 May, 24 July, and 15 Oct. 2018, and 16 and 29 May, 22 July, and 15 and 17 Oct. 2019 'Arbequina' cuttings were taken from mature trees in an established orchard and grower collaborator site in Dayton, OR, USA (45°15'22.40"N, 123° 3'29.89"W.) These dates corresponded to seasons identified as spring, summer, and fall, respectively. Shoots roughly 0.3 m long, semi-hardwood, of the previous season's growth were selected, and trimmed to obtain 24 7.5 cm cuttings (replicates) of each cultivar per treatment. Experimental design for hormone treatments assigned to cuttings in trays in the greenhouse was completely randomized. Data was analyzed as a 4-factor randomized complete block design with year (two levels), site (two levels), season (three levels), and hormone (four levels) as factors, for a total of 1,152 experimental units.

*Hormone treatment.* Cuttings were dipped in one of the following four treatments: 1) 3000ppm IBA rooting hormone powder (Hormex no. 3; Maia Products, Inc., Westlake Village, CA, USA; referred to as "3H"), 2) 8000ppm IBA rooting hormone powder (Hormex no. 8; Maia Products, Inc., referred to as "8H"), 3) 2000ppm IBA + 1000ppm NAA (Dip'N Grow; 1.0% IBA + 0.5% NAA; Clackamas, OR, USA; referred to as "2D"), and 4) 4000ppm IBA + 2000ppm NAA solution (Dip'N Grow; 1.0% IBA + 0.5% NAA; Clackamas, OR, USA; referred to as "4D"). Cuttings assigned to the IBA treatments were dipped in water prior to being dipped in the IBA powder. The IBA + NAA solutions were prepared from a stock solution of 10,000ppm IBA + 5,000ppm NAA, mixed with water to achieve the desired concentration. Potting media was prepared as a 1 horticultural peat moss : 1 coarse propagation grade perlite (by volume; Supreme Perlite Co.; Portland, OR, USA). "Coarse propagation grade perlite" refers to a mix of coarse (4760 µm, medium (2380 µm) and fine (1190 µm) grains. Media was used to fill trays containing 32 individual cells measuring 6.67 cm in diameter.

*Study sites.* Pots were arranged in trays in a heated greenhouse on benches with bottom heat set at 22.22 °C and a Gemini 6A automatic misting controller (Phytotronics, Inc; Earth City, MO, USA) with Netafim CoolNet Pro fogger nozzles (Netafim USA; Fresno, CA, USA) with 30.7 L·hr–1 flow, at the Oregon State University North Willamette Research and Extension Center (NWREC) in Aurora, OR (45°16'49.65"N, 122°45'1.94"W) and at the grower site in Dayton where cuttings were collected. Irrigation at NWREC was set to a range of 8-20 seconds of mist every 6-20 minutes, adjusted as needed based on daily temperature fluctuations. Irrigation at the grower site was managed using similar environmental controls, though upon periodic inspection of cuttings at grower site, watering did not appear to be as consistent as at the research station, and occasionally cells were dry. In 2019, a temperature and relative humidity logger (HOBO MX2301; Onset Computer Corp.; Bourne, MA, USA) was installed at both locations to monitor hourly greenhouse conditions; however a battery failure in the grower site logger caused a halt in data collection at the start of the fall propagation trial that year.

In Spring 2019, the greenhouse at NWREC experienced a power failure, causing fans and the mist clock to cease operation, resulting in the loss of all cuttings. Cuttings were collected from the grower site again on 29 May 2019, and this second sticking was replicated at the grower site as well, though they did not experience a power loss. This has resulted in two spring timings for 2019, referred to as Spring 1 (grower site only) and Spring 2 (NWREC and grower site). The research team noted that upon re-collection of cutting material for Spring 2, trees had begun forming flower buds, and finding cutting material that did not show signs of transitioning to floral development was difficult.

*Low-input complimentary trial.* There was an additional trial at NWREC only conducted in Fall 2018 and 2019, replicating the hormone treatments, but instead of placing trays under automated mist, plastic tray covers were placed over the cuttings with occasional hand watering and misting for a lower input approach. Experimental design for hormone treatments assigned to cuttings in trays in the greenhouse was completely randomized. Data was analyzed as a 3-factor randomized complete block design with year (two levels), irrigation (two levels) and hormone (four levels) as factors with 24 replicates, for a total of 384 experimental units. All trial preparation, management, and data collection and analysis were otherwise identical to the overall seasonality and hormone trial.

*Data analysis.* Data were collected roughly 90 days after sticking, on the following dates: 23 Aug. 2018, 19 Oct. 2018, and 15 Jan. 2019; and 9 and 27 Aug. 2019, 21 Oct. 2019 and 21 Jan. 2020. We counted the number of primary roots longer than 5 mm per cutting and measured combined total root length of all primary roots longer than 5 mm. Rooting percentage was recorded, counting cuttings that developed any roots, including those less than 5 mm long, as rooted, and those with no roots or only callus formation considered as not rooted. Data were analyzed using R software (version 3.5.2; R Foundation for Statistical Computing, Vienna, Austria). Treatment effects were examined by analysis of variance using linear models (R package lm) for root number and length, and generalized linear mixed models (R package lmer) for rooting percentage, both of which assume errors are normally distributed. Percentage data was initially analyzed using binomial generalized linear mixed models; however the model did not fit the data well, and so the research team decided to use a GLMM with a normal distribution, based on Cirillo et al. (2017), Denaxa et al. (2011), Hecmi et al. (2013), Isfendiyaroglu (2009), and Khajehpour et al. (2014). For significant treatment effects, treatment differences were determined using the Tukey-Kramer honestly significant difference test (at $P \leq 0.05$). For analyses across both years and sites, only the Spring 2 data from 2019 at the grower site was utilized, to maintain a balanced design, and because this date was closer to the single spring date from 2018.

**Results**

*NWREC/Aurora.* Root number was highest in Spring 2018, but lowest in Spring 2019 (Table 3.1). Propagation season influenced rooting hormones, with the combination of the spring season with 8H showing increased root numbers, the summer and 4D having the lowest root number, and other combinations showing a varied response.

The greatest root length occurred in Spring 2018, with lowest root lengths in Spring 2019, and fall regardless of year. Spring-3H, spring-8H, and summer-3H yielded the greatest root lengths, with the lowest root lengths seen with 2D, 4D, and 8H in fall.

The highest rooting percentages were seen in Spring and Fall 2018, though these same seasons in 2019 had the lowest rooting percentages. There were few differences between hormone treatments across seasons with regards to rooting percent, with summer-2D having the highest percent, and summer 4D the lowest.

*Grower site/Dayton.* 2D and 3H treatments had the highest number of roots in 2018, while all other year-hormone combinations excluding 2019-8H had the lowest root numbers (Table 3.2). Spring and summer-3H treatments led to the highest root numbers, with these same seasons and the 4D hormone associated with the lowest root numbers.

The greatest root length was seen in Fall 2018, with the lowest root length in Summer 2019. Similar to the results for root number, 2D and 3H in 2018 lead to the greatest root length, with all other treatment combinations lower. The fall-2D treatment combination yielded the greatest root length, and the shortest root length was seen with summer-4D, with other treatment combinations having a varied response.

The highest rooting percentage occurred with 3H in 2018. The lowest percentages were seen with 4D in either year, and 8H in 2018. When looking at the effect of season in combination with hormone, spring with the 3H hormone was associated with the highest rooting percentage, compared to summer-4D with the lowest percentage.

*Site comparison.* Averaged across all seasons, there was an increase in root number at the Aurora site in 2018, with the fewest number of roots at the Dayton site in 2019 (Table 3.3). The highest root number was seen at the Aurora site in spring, and the lowest numbers at Dayton in summer and spring. Averaging across both trial sites, the highest root number was seen in Spring 2018 followed by Fall 2018, with the lowest numbers in Spring 2019 and summer both years. The combination of spring with 3H and 8H, summer with 3H, and fall with 2D were associated with the highest root numbers. 4D utilized in the spring and summer yielded the lowest root numbers.

Once again spring and summer at the Aurora site were associated with the greatest root lengths while spring and summer at the Dayton site showed the shortest root lengths. Averaging across sites, Spring 2018 and Fall in 2018 were also associated with the greatest root lengths, and the shortest root lengths were seen in Spring 2019 and Fall 2019. Similarly for root number, spring with the 3H and 8H hormone, and summer with 3H demonstrated the greatest root lengths with 4D in the spring and summer showing the shortest lengths.

The highest rooting percentages occurred in spring, summer, and fall at Aurora, and the lowest percentages in spring and summer at the Dayton site. There was less variation in rooting percentages averaged across site and hormone, with the highest percentages seen in Spring 2018 and Fall 2018, and all other treatments lower. The best performing combinations of season and hormone were 2D in fall and 3H in spring and summer. The lowest percentages were associated with 4D in spring and summer, which is consistent with root number and length results.

*Low input complimentary trial/Aurora.* Higher numbers were seen in 2018 for root number, root length, and rooting percent (Table 3.4). The irrigation method (mist vs. non-mist) did not show a significant effect on any response variable. 3H was associated with a 79% rooting percentage, while 4D showed the least rooting with 63%.

**Discussion**

This trial showed overall improved rooting at NWREC in Aurora, compared to the grower site in Dayton. Researchers noted that while there was an attempt to maintain consistency between sites in terms of greenhouse temperatures, and use of bottom heat and mist cycles, watering appeared to be occasionally inconsistent at the grower site, with some cells in the tray drier than others. Additionally, the grower site greenhouse was smaller, with some shading due to nearby trees. Despite the apparent shading, the temperature sensors placed in the greenhouse mist benches in 2019 demonstrate that over both spring and summer 2019 propagation seasons, the grower site tended to have higher temperatures and higher relative humidity (as shown in Figs. 3.1-3.4). It is unknown how these higher temperatures and humidity levels may have contributed to slightly decreased root numbers, lengths, and percentages at the grower site.

Higher root numbers, lengths, and percentages were also seen in 2018 compared to 2019. This was most strongly impacted by the increased numbers seen in Spring 2018 at NWREC in Aurora, where rooting percentages ranged from 75%-96%, and the 3H treatment in particular yielded a maximum root number of 13. Although the second spring sticking date in 2019 corresponded more closely with the single spring 2018 date than the first spring date of 2019, the developmental stage of the shoots appeared to be further along in 2019 by the time of wood collection. It was difficult to find wood that was not yet showing floral development. Wood that was collected at the single spring sticking date in 2018 may have been at a more optimal stage of development for responding to the synthetic rooting hormone treatment, leading to better rooting results during that season and year. Numerous studies have explored the effect of endogenous carbohydrate levels in olive wood, their change throughout the seasons, and their impact on propagation success with varying concentrations and combinations of synthetic rooting hormones (Denaxa et al., 2011 and 2012); however, our study did not evaluate this characteristic of the wood.

The interaction between seasonality of propagation and wood age, and rooting hormone concentration and combination is well documented in the literature and is reflected in the current study. When evaluating the best treatment combination amongst three seasons and four hormone concentration-combinations, there are multiple pairs that perform well, some that are intermediate, and others that show poor rooting performance. Spring propagation shows high root numbers, lengths, and percentages with all hormones except for 4D, which is often among the lowest numbers. This is comparable to the high root numbers and rooting percentages seen in spring propagation of ‘Leccino’ with 3000ppm IBA in Ahmed et al. (2002), and high rooting percentages of ‘Ortolana’ and ‘Racioppella’ cultivars (Cirillo et al., 2017) and ‘Manzanilla’, also in spring (Khajehpour et al., 2014). Summer typically shows decreased numbers with all treatments except for 3H, which is often among the highest. Fall rooting is somewhat inconsistent with high root numbers and percentages for all hormone treatments, but low root lengths. Future studies are needed to determine which of these factors play the largest role in long-term cutting survival. Overall, these results may be compared to Denaxa et al.’s 2011 study in Greece, which found high rooting percentages for ‘Arbequina’ propagated in summer with a 2000ppm IBA hormone, and fall with a combination 1000ppm IBA+NAA hormone. These treatments are similar to the 3H (3000ppm IBA) and 2D (2000pppm IBA and 1000ppm NAA) treatments, and furthermore, align with the success of summer-3H and fall-2D (low root lengths excluded) seen in the current trial. However, Denaxa et al.’s follow-up study (2012) showed a lower rooting percentage for ‘Arbequina’ propagated in spring with the treatment similar to 3H, compared to a higher rooting percentage in summer with the same hormone treatment. It is not clear why these treatments performed so differently in Denaxa et al., while they were among the best performing treatment combinations in the present study.

There are few other studies comparable to the present low input complimentary trial in terms of evaluating alternatives to mist systems for propagation. Özkaya and Çelik (1994) demonstrated overall higher rooting with use of a non-misted, shaded polyethylene tunnel compared to a mist system for high-rooting-capacity 'Gemlik' and low-rooting-capacity 'Domat' during spring propagation in Turkey, which was the only season included in their study. It is unclear how this study was able to maintain a high humidity environment during the warmer spring months, which would likely have not performed as well as the non-misted covered trays used in fall propagation in the present study.

**Conclusion**

Part 1 of this study demonstrates that, depending on propagation season and age of wood, rooting hormone concentration and combination, we were able to achieve high rates of rooting with 'Arbequina' olives. Future studies are needed to determine if root number and length, or rooting percentage are better determinants of long-term survival of propagated cuttings, as some treatments did not show consistent results across these three response variables. It is also worth exploring if the practices evaluated in these studies will lead to successful propagation of additional cultivars of interest to Oregon growers.

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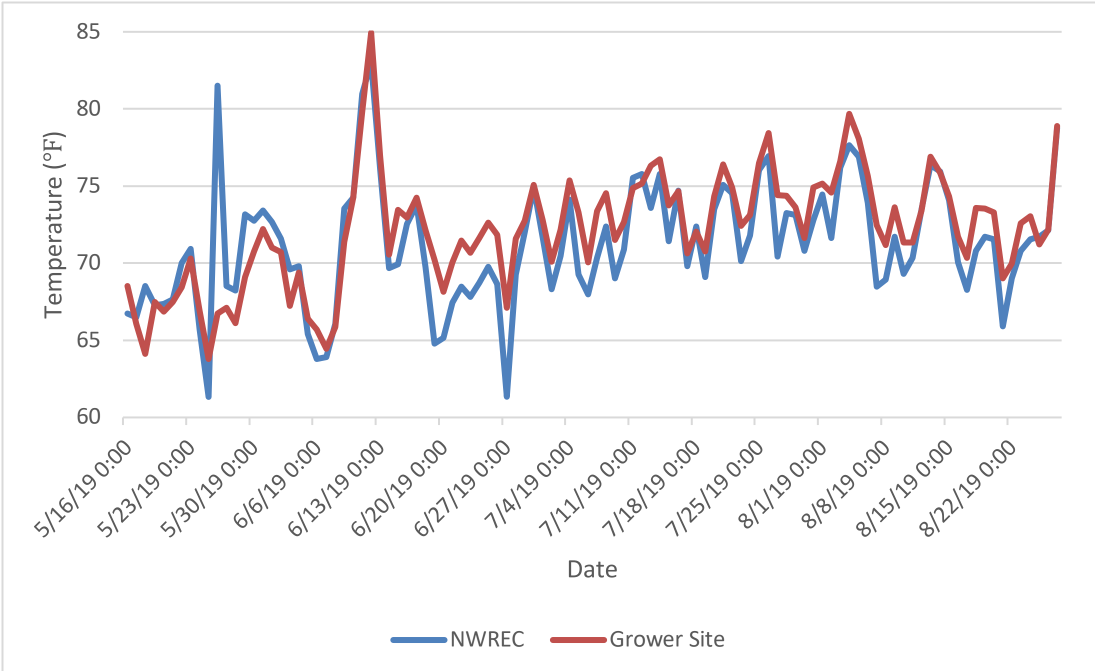


Fig. 3.1. Daily average greenhouse mist bench temperatures at NWREC (Aurora, OR) and grower site (Dayton, OR) Spring 2019. Data collected with Onset HOBO MX2301 temperature and RH sensor.

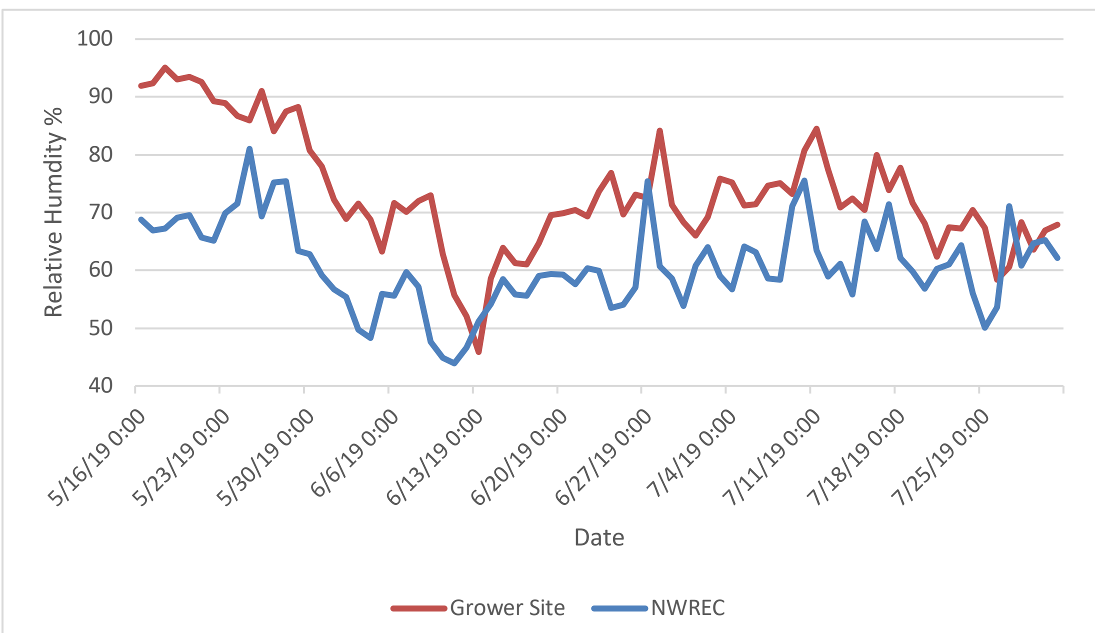


Fig. 3.2. Daily average greenhouse mist bench relative humidity at NWREC (Aurora, OR) and grower site (Dayton, OR) Spring 2019. Data collected with Onset HOBO MX2301 temperature and RH sensor.

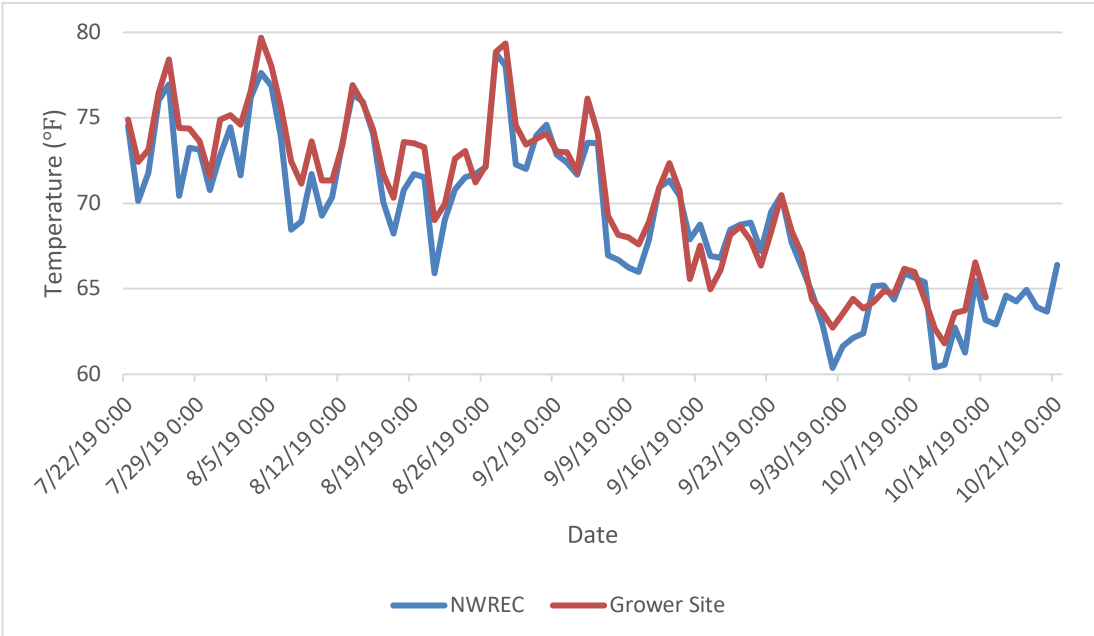


Fig. 3.3. Daily average greenhouse mist bench temperatures at NWREC (Aurora, OR) and grower site (Dayton, OR) Summer 2019. Data collected with Onset HOBO MX2301 temperature and RH sensor.

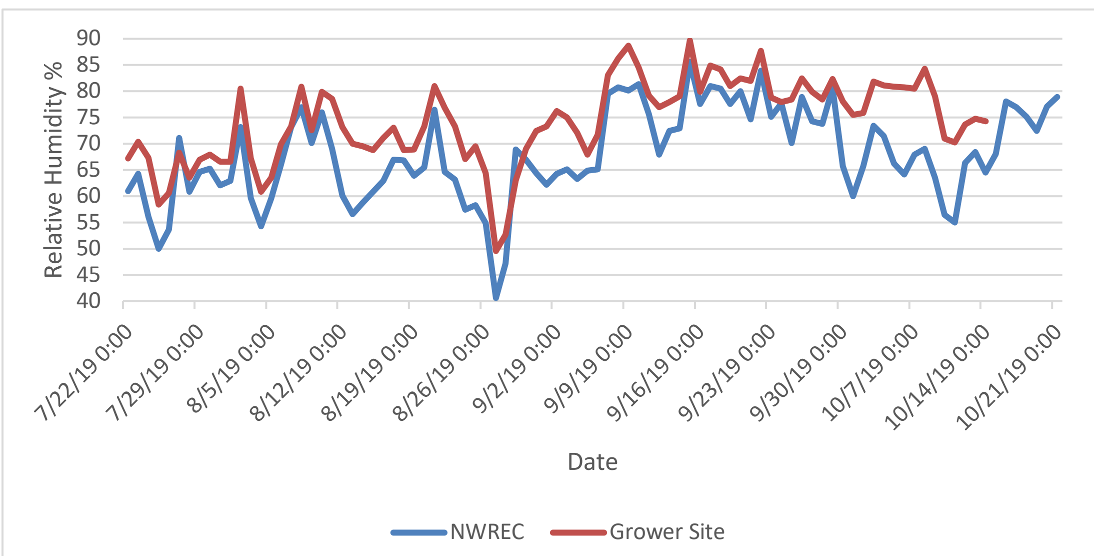


Fig. 3.4. Daily average greenhouse mist bench relative humidity at NWREC (Aurora, OR) and grower site (Dayton, OR) Summer 2019. Data collected with Onset HOBO MX2301 temperature and RH sensor.

Table 3.1. Effect of year and rooting hormone and concentration on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Arbequina' olive cuttings grown for approx. 90 days with overhead mist in a heated greenhouse, at the North Willamette Research and Extension Center in Aurora, OR, 2018 and 2019 (n = 24).

| Treatments | No. of Primary Roots | | | Total Root Length (cm) | | | Rooting Percentage (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Season** | | | **Season** | | | **Season** | |
| **Year** | Spring | Summer | Fall | Spring | Summer | Fall | Spring | Summer | Fall |
| 2018 | 9 a[z] | 5 b | 5 b | 52 a | 28 bc | 21 cd | 90 a | 73 ab | 84 a |
| 2019 | 2 c | 4 b | 4 bc | 22 cd | 32 b | 16 d | 65 bc | 76 ab | 54 c |
| | | **Season** | | | **Season** | | | **Season** | |
| **Hormone[y]** | Spring | Summer | Fall | Spring | Summer | Fall | Spring | Summer | Fall |
| 2D | 5 abc | 5 abc | 4 bc | 36 bc | 38 ab | 16 d | 75 ab | 90 a | 65 ab |
| 4D | 4 bc | 3 c | 4 bc | 23 bcd | 19 c | 19 d | 63 ab | 60 b | 69 ab |
| 3H | 6 ab | 6 ab | 5 bc | 48 a | 41 a | 21 cd | 88 ab | 83 ab | 73 ab |
| 8H | 7 a | 4 bc | 4 bc | 42 a | 24 bcd | 18d | 83 ab | 65 ab | 71 ab |
| **Significance[x]** | | | | | | | | | |
| *Year(Y)* | | <.0001 | | | <.0001 | | | <.0001 | |
| *Season(S)* | | 0.0024 | | | <.0001 | | | ns | |
| *Hormone(H)* | | 0.0004 | | | <.0001 | | | 0.0036 | |
| *Y x S* | | <.0001 | | | <.0001 | | | 0.0001 | |
| *Y x H* | | ns | | | ns | | | ns | |
| *S x H* | | 0.0028 | | | 0.0001 | | | 0.0234 | |
| *Y x S x H* | | 0.0114 | | | ns | | | ns | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]For hormone treatments 2D = 'Dip'N Grow' 2000ppm IBA + 1000ppm NAA, 4D = 'Dip'N Grow' 4000ppm IBA + 2000ppm NAA, 3H = 'Hormex' 3000ppm IBA, and 8H = 'Hormex' 8000ppm IBA.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.2. Effect of year, season, and rooting hormone and concentration on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Arbequina' olive cuttings grown for approx. 90 days with overhead mist in a heated greenhouse, at the grower collaborator site in Dayton, OR, 2018 and 2019 (n = 24).

| Treatments | No. of Primary Roots | | | | Total Root Length (cm) | | | | Rooting Percentage (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Season** | | | | | | | |
| **Year** | | | | | Spring | Summer | | Fall | | | | |
| 2018 | 4 | | | | 18 b[z] | 12 bc | | 28 a | 54 | | | |
| 2019 | 3 | | | | 11 bc | 9 c | | 13 bc | 46 | | | |
| | **Hormone[y]** | | | | **Hormone** | | | | **Hormone** | | | |
| **Year** | 2D | 4D | 3H | 8H | 2D | 4D | 3H | 8H | 2D | 4D | 3H | 8H |
| 2018 | 5 a | 2 b | 5 a | 2 b | 27 a | 11 b | 29 a | 10 b | 67 ab | 32 c | 76 a | 40 c |
| 2019 | 3 b | 2 b | 3 b | 3 ab | 12 b | 6 b | 12 b | 15 b | 49 bc | 31 c | 54 abc | 50 bc |
| | **Hormone** | | | | **Hormone** | | | | **Hormone** | | | |
| **Season** | 2D | 4D | 3H | 8H | 2D | 4D | 3H | 8H | 2D | 4D | 3H | 8H |
| Spring | 4 abc | 1 d | 4 ab | 2 bcd | 18 bcd | 5 ef | 24 ab | 11 cdef | 58 abc | 29 cd | 75 a | 48 abc |
| Summer | 2 cd | 1 d | 5 ab | 2 cd | 8 def | 2 f | 22 abc | 9 def | 44 bc | 10 d | 73 ab | 33 cd |
| Fall | 6 a | 4 abc | 3 bcd | 4 abc | 32 a | 18 bcd | 15 bcde | 17 bcde | 71 ab | 54 abc | 48 abc | 54 abc |
| **Significance[x]** | | | | | | | | | | | | |
| *Year(Y)* | 0.0022 | | | | <.0001 | | | | 0.0401 | | | |
| *Season(S)* | <.0001 | | | | <.0001 | | | | 0.0014 | | | |
| *Hormone(H)* | <.0001 | | | | <.0001 | | | | <.0001 | | | |
| *Y x S* | ns | | | | 0.0143 | | | | ns | | | |
| *Y x H* | <.0001 | | | | <.0001 | | | | 0.0124 | | | |
| *S x H* | <.0001 | | | | <.0001 | | | | <.0001 | | | |
| *Y x S x H* | ns | | | | 0.0067 | | | | ns | | | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]For hormone treatments 2D = 'Dip'N Grow' 2000ppm IBA + 1000ppm NAA, 4D = 'Dip'N Grow' 4000ppm IBA + 2000ppm NAA, 3H = 'Hormex' 3000ppm IBA, and 8H = 'Hormex' 8000ppm IBA.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.3. Effect of site, year, season, and rooting hormone and concentration on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Arbequina' olive cuttings grown for 93 (2018) and 99 (2019) days with overhead mist in a heated greenhouse, at the North Willamette Research and Extension Center in Aurora, OR and the grower collaborator site in Dayton, OR, 2018 and 2019 (n = 24).

| Treatments | No. of Primary Roots | | | | Total Root Length (cm) | | | | Rooting Percentage (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Year** | | | | | | | | | | |
| **Site** | 2018 | | 2019 | | | | | | | | | |
| Aurora | 6 a | | 4 b | | | 29 | | | | 74 | | |
| Dayton | 4 b | | 3 c | | | 15 | | | | 50 | | |
| | | **Season** | | | | **Season** | | | | **Season** | | |
| **Site** | Spring | Summer | | Fall | Spring | Summer | | Fall | Spring | Summer | | Fall |
| Aurora | 6 a | 5 ab | | 4 b | 37 a | 30 b | | 19 c | 78 a | 74 a | | 69 ab |
| Dayton | 3 c | 2 c | | 4 b | 15 cd | 10 d | | 21 c | 53 cd | 40 d | | 57 bc |
| | | **Season** | | | | **Season** | | | | **Season** | | |
| **Year** | Spring | Summer | | Fall | Spring | Summer | | Fall | Spring | Summer | | Fall |
| 2018 | 6 a | 3 c | | 5 b | 35 a | 20 bc | | 24 b | 71 a | 58 b | | 74 a |
| 2019 | 2 d | 3 cd | | 3 c | 17 c | 20 bc | | 15 c | 58 b | 56 b | | 52 b |
| | | **Hormone**[y] | | | | **Hormone** | | | | **Hormone** | | |
| **Season** | 2D | 4D | 3H | 8H | 2D | 4D | 3H | 8H | 2D | 4D | 3H | 8H |
| Spring | 5 abc | 2 de | 5 ab | 5 ab | 27 abc | 14 ef | 36 a | 27 abc | 67 abc | 46 cd | 81 a | 66 abc |
| Summer | 4 bcde | 2 e | 5 a | 3 cde | 23 bcde | 10 f | 32 ab | 16 def | 67 abc | 35 d | 78 a | 49 bcd |
| Fall | 5 ab | 4 abcd | 4 abcde | 4 abcd | 24 bcd | 19 cdef | 18 cdef | 18 cdef | 68 ab | 61 abc | 60 abc | 63 abc |
| **Significance**[x] | | | | | | | | | | | | |
| *Site (S)* | | <.0001 | | | | <.0001 | | | | <.0001 | | |
| *Year(Y)* | | <.0001 | | | | <.0001 | | | | <.0001 | | |
| *Season(T)* | | 0.0022 | | | | <.0001 | | | | 0.0482 | | |
| *Hormone(H)* | | <.0001 | | | | <.0001 | | | | <.0001 | | |
| *S x Y* | | <.0001 | | | | ns | | | | ns | | |
| *S x T* | | <.0001 | | | | <.0001 | | | | 0.0029 | | |
| *S x H* | | ns | | | | ns | | | | ns | | |
| *Y x T* | | <.0001 | | | | <.0001 | | | | 0.0050 | | |
| *Y x H* | | ns | | | | ns | | | | ns | | |
| *T x H* | | <.0001 | | | | <.0001 | | | | <.0001 | | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]For hormone treatments 2D = 'Dip'N Grow' 2000ppm IBA + 1000ppm NAA, 4D = 'Dip'N Grow' 4000ppm IBA + 2000ppm NAA, 3H = 'Hormex' 3000ppm IBA, and 8H = 'Hormex' 8000ppm IBA.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.4. Effect of year, propagation method, and rooting hormone and concentration on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Arbequina' olive cuttings grown for approx. 90 days with and without overhead mist in a heated greenhouse, at the North Willamette Research and Extension Center in Aurora, OR, Fall 2018 and 2019 (n = 24).

| Treatments | No. of Primary Roots | Total Root Length (cm) | Rooting Percentage (%) |
|---|---|---|---|
| **Year** | | | |
| 2018 | 5 a[z] | 20 a | 83 a |
| 2019 | 4 b | 17 b | 58 b |
| **Method** | | | |
| Misted | 4 | 19 | 69 |
| Non-misted | 4 | 19 | 72 |
| **Hormone**[y] | | | |
| 2D | 4 | 17 | 65 ab |
| 4D | 4 | 16 | 63 b |
| 3H | 5 | 22 | 79 a |
| 8H | 5 | 19 | 76 ab |
| **Significance**[x] | | | |
| *Year(Y)* | 0.0011 | 0.0469 | <.0001 |
| *Method(M)* | ns | ns | ns |
| *Hormone(H)* | ns | ns | 0.0156 |
| *Y x M* | ns | ns | ns |
| *Y x H* | ns | ns | ns |
| *M x H* | ns | ns | ns |
| *Y x M x H* | ns | ns | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]Hormone treatments included: 'Dip'N Grow' 2000ppm IBA + 1000ppm NAA, 'Dip'N Grow' 4000ppm IBA + 2000ppm NAA, 'Hormex' 3000ppm IBA, and 'Hormex' 8000ppm IBA.
[x]*P* value provided unless non-significant (ns; $P \geq 0.05$).

### 3.2: Impact of Cultivar Rooting Ability and Media

**Abstract**

Successful olive propagation depends upon cultivar rooting ability, and media and hormone used. This second in a two-part study consisted of two subtrials and evaluated rooting media and hormone for 'Leccino' and 'Picual' (high and intermediate rooting capacity, respectively) in on-farm propagation in Oregon, USA. In the first trial, cuttings were collected from a mature orchard in Dayton, OR and propagated in 1 peat : 1 perlite (by volume), 3 peat : 7 perlite, 1 peat : 1 coconut coir, and 3 perlite : 7 perlite media in Spring 2019 and 2020. In the second trial, cuttings were propagated using 1 peat : 1 perlite (by volume) media and a low rate of indole-3-butyric acid (IBA) alone (referred to as 3H) and IBA in combination with naphthalene acetic acid (NAA; referred to as 2D) in Spring 2020. Trials were conducted in Aurora and Dayton, Oregon. In the first subtrial, results differed between sites, with the effects of rooting hormone impacted by year at the research station, and hormone interacting with cultivar at the grower site. Greatest root numbers, lengths, and percentages occurred with the peat and perlite media mixes. 'Leccino' had greater root length with the peat and perlite mixes than with other media treatments. In the second subtrial, 'Picual' had greater root number and length than 'Leccino', as did the 2D hormone compared to 3H. Rooting percentage varied depending on cultivar and hormone, with 65-81% rooting occuring with 'Picual', and 75% rooting for 'Leccino' with 2D, compared to 25% rooting for 'Leccino' with 3H. Findings suggest that rooting ability of cultivars may differ in Oregon's climate compared to other regions, and that with media and hormone treatments selected specifically for each cultivar, both 'Leccino' and 'Picual' may be successfully propagated.

**Introduction**

Olive (*Olea europaea*) cultivars show a range of rooting ability when propagated via vegetative cuttings (Fabbri et al., 2004). High rooting ability (66%-100%) cultivars include 'Arbequina', 'Leccino', and 'Mission'; intermediate (33%-66%) includes 'Kalamata', 'Picual', and 'Taggiasca'; and 'Domat', 'Empeltre', and

‘Farga’ are among those considered to be harder to root (0%-33%) (Fabbri et al., 2004).

Studies have evaluated factors that may interact with cultivar and increase or decrease propagation success in olives, including seasonality of propagation and hormone rate. Denaxa et al. (2019) and Khabou and Trigui (1999) explored the effect of propagation season or timing on the rooting success of multiple cultivars. Denaxa et al. demonstrated propagation season affecting easy-to-root ‘Arbequina’ and to a lesser extent, hard-to-root ‘Kalamata’, which had low rooting regardless of season (2019). Meanwhile, Khabou and Trigui (1999) showed highest rooting in December, though there was a nearly 40% difference in rooting ability between the cultivars studied. Others have focused on the interaction between cultivar and rooting hormone concentration or type. Cirillo et al. (2017) found that among 20 different Italian cultivars, only eight were considered to have sufficient rooting ability, which was highly variable based on season, hormone type, as well as specific part of the shoot used to create the cutting. Looking exclusively at the impact of hormone on cultivar rooting ability, Khattak et al. found that ‘Domate’ responded to higher levels of IBA, ‘Nocellara Del Belice’ rooted with a range of hormone concentrations, and other cultivars demonstrated a lack of response (2001). Similarly, Talaie and Zohouri (2019) saw cultivars responding to either 2000ppm or 4000ppm IBA.

Fewer studies have examined the impact of rooting media on cultivar rooting ability. Fabbri et al.() state that the most common rooting media or substrate is perlite, followed by peat, vermiculite, sand, and combinations of these materials (2004). Studies on rooting media often evaluate locally available materials, such as manure and rockwool (Awan et al., 2003; Isfendiyaroglu et al., 2009). Both sand and perlite alone and in combination stand out as high performing substrates in the literature (Awan et al., 2003), with Hecmi et al. (2013) showing an association between sand and high rooting percentage, and perlite and high root numbers and lengths, with results varying based on cultivar. Meanwhile, in Hosseini et al., (2008), the two cultivars evaluated showed highest rooting with different substrates, with ‘Zard’ having a higher rooting percentage in 100% perlite, and ‘Roghani’ performing better in a sand and perlite mix.

This range of responses to the factors involved in propagation indicates the importance of research on locally important and available cultivars and rooting media, and the development of best practices for specific growing regions. Building off the results of part 1 of our two-part study investigating on-farm olive propagation in Oregon, in which wood collected and propagated in spring and the use of lower concentration rooting hormones demonstrated overall best rooting, part 2 adapts these practices to propagation of 'Leccino' and 'Picual'. These cultivars are widely grown by Oregon olive producers (Barker and Fernandez-Salvador, unpublished data), and as stated above are considered to be of high and intermediate rooting ability, respectively.

The objectives of part 2 of this study were 1) to evaluate the impact of media on rooting success during spring propagation for two potentially cold-hardy cultivars with previously established differences in rooting ability, and 2) utilize results from the preceding trials to determine the impact of cultivar rooting ability and rooting hormone concentrations in the most successful media mix, at the timing identified in part 1 as most conducive to olive rooting in Oregon's climate. These two objectives are tied to two separate trials, referred to as the 2019 and 2020 Cultivar Rooting Ability and Media Trial, and the 2020 Compilation Trial, respectively.

**Materials and methods**

*2019 and 2020 Cultivar Rooting Ability and Media Trial.* On 16 and 29 May 2019 and 12 May 2020 cuttings of 'Leccino' and 'Picual' were taken from the grower collaborator site in Dayton as described in part 1. Similar age wood was collected, to obtain 16 7.5 cm cuttings (replicates) of each cultivar per treatment. Experimental design for hormone treatments assigned to cuttings in trays in the greenhouse was completely randomized. Data was analyzed as a 4-factor randomized complete block design with year (two levels), site (two levels), cultivar (two levels) and media treatment (four levels) as factors, for a total of 512 experimental units. Potting media treatments were prepared as follows: 1) 1 horticultural peat moss : 1 coarse propagation grade perlite (by volume; Supreme Perlite Co.; Portland, OR, USA; referred to as "PP11"), 2) 3 horticultural peat moss : 7 coarse propagation grade perlite (by volume, referred to as "PP37"), 3) 1 coconut coir : 1 coarse propagation grade perlite (by volume, referred to as “CP11”), and 4) 3 coconut coir : 7 coarse propagation grade perlite (by volume, referred to as “CP37”). Coconut coir was fully hydrated prior to mixing media. Media was used to fill trays at the North Willamette Research and Extension Center (NWREC) in Aurora, OR, as described in part 1. Cuttings were dipped in water followed by 3000ppm indole-3-butyric acid (IBA) rooting hormone powder (Hormex no. 3; Maia Products, Inc., Westlake Village, CA, USA) and planted in cells in trays in a greenhouse at NWREC and at the grower site in Dayton, OR, as described in part 1. A greenhouse power loss at NWREC impacted this trial, and 2019 cuttings for NWREC had to be re-collected on 29 May 2019. Cuttings were not re-stuck at grower site, as timing was not a treatment in this study.

*Data analysis.* Data were collected on 8 Sept. 2019 (103 days from sticking at NWREC, and 116 days from sticking at grower site), and 14 Aug. 2020 (95 days) at the NWREC and 11 Sept. 2020 (117 days) at the grower site. Variation in days from sticking to evaluation were due to the slower rooting of these cultivars, and an attempt to get as close as possible to 90 days, while still having sufficient rooting taking place in order to evaluate. Data were analyzed using R software (version 3.5.2; R Foundation for Statistical Computing, Vienna, Austria). Treatment effects were examined by analysis of variance using linear models (R package lm) for root number and length, and generalized linear mixed models (GLMM) (R package lmer) for rooting percentage, both of which assume errors are normally distributed. For significant treatment effects, treatment differences were determined using the Tukey-Kramer honestly significant difference test (at $P \leq 0.05$).

*2020 Compilation Trial.* On 12 May 2020 cuttings of ‘Leccino’ and ‘Picual’ were taken from the same Dayton orchard as described above. Similar age wood was collected, to obtain 24 7.5 cm cuttings (replicates) of each cultivar per treatment. Experimental design for hormone treatments assigned to cuttings in trays in the greenhouse was completely randomized. Data was analyzed as a 3-factor randomized complete block design with site (two levels), cultivar (two levels) and hormone treatment (two levels) as factors, for a total of 192 experimental units. The 1 peat : 1 perlite (by volume) media as prepared for previous trials was used to fill trays as described above. Cuttings were dipped in 1) water followed by 3000ppm IBA rooting hormone powder (Hormex no. 3; Maia Products, Inc., Westlake Village, CA, USA) or 2) 2000ppm IBA + 1000ppm 1-Naphthaleneacetic acid (NAA) solution (Dip'N Grow; 1.0% IBA + 0.5% NAA, diluted with water to treatment concentration; Clackamas, OR, USA; referred to as "2D"), and planted in cells in trays in a greenhouse as described previously. The experiment was replicated at the grower site as in preceding trials. Data were collected 98 days later, on 17 Aug. 2020, and analyzed as described above.

**Results**

*2019 and 2020 Cultivar Rooting Ability and Media Trial, NWREC/Aurora.* 'Picual' cuttings showed 5 primary roots on average across 2019 and 2020, compared to 'Leccino' with 3 primary roots (Table 3.5). The PP11 rooting media had the highest root number, while both coir : perlite media treatments had the lowest root numbers.

PP11 in both years was associated with the greatest root length, and CP11 in 2019 showed the shortest length.

All peat : perlite treatments across both years, and CP11 in 2020 showed the highest rooting percentages. CP11 in 2019 had an extremely low rooting percentage of 6%.

*2019 and 2020 Cultivar Rooting Ability and Media Trial, grower site/Dayton.* 'Picual' showed a greater number of roots than 'Leccino' (Table 3.6). PP11 media was associated with an increased root number, while the CP37 treatment yielded the lowest root number.

'Picual' showed a greater root length in 2019, compared to 'Leccino' in either year having the shortest root length. 'Picual' rooted in PP11 media was associated with the highest root length, and 'Leccino' rooted with CP37 showed the shortest root length.

All treatments averaged across 2019 showed a 68% rooting percent, compared to 52% in 2020.

*2019 and 2020 Cultivar Rooting Ability and Media Trial, site comparison.* Averaging across both sites, 'Picual' showed a greater root number than 'Leccino'

(Table 3.7). The PP11 media yielded higher root numbers than the two coir : perlite media treatments.

‘Picual’ and ‘Leccino’ in 2019 were associated with the greatest and shortest root lengths respectively. Both peat : perlite media treatments showed increased root length compared to both coir : perlite media treatments. There was an interaction between site, cultivar, and media for root length.

The highest rooting percentage was seen in Dayton in 2019, while the lowest rates occurred in Aurora in 2019 and Dayton in 2020. PP11 had the highest rooting percentage, and CP37 showed the lowest percentage. There was an interaction between site, year, and media for rooting percentage.

*2020 Compilation Trial, NWREC/Aurora.* ‘Picual’ with both 2D and 3H hormones was associated with higher root numbers compared to ‘Leccino’ with 3H, which had the lowest root number (Table 3.8). For both root length and rooting percentage, ‘Picual’ with either hormone and 2D with either cultivar was associated with the greatest root length and rooting percentage, compared to ‘Leccino’ with 3H, respectively, which performed least well in both cases.

*2020 Compilation Trial, grower site/Dayton.* ‘Picual’ showed an increased root number compared to ‘Leccino’ (Table 3.9). The 2D hormone was associated with a higher root number in contrast to 3H. Similar effects were seen for root length, with ‘Picual’ and the 2D hormone treatments showing greater root lengths. ‘Picual’ and the 2D hormone were also associated with the greatest rooting percentages at 60% and 63%, compared to the 38% and 35% achieved with ‘Leccino’ and 3H.

*2020 Compilation Trial, site comparison.* The Aurora site had the greater root number, length, and percentage, compared to the Dayton site (Table 3.10). ‘Picual’ also had a greater number of roots and root length compared to ‘Leccino’. ‘Picual’ propagated with either hormone, and ‘Leccino’ with 2D had the highest rooting percentage, while ‘Leccino’ propagated 3H had the lowest rooting percentage.

**Discussion**

*2019 and 2020 Cultivar Rooting Ability and Media Trial.* This trial showed higher root numbers and lengths for ‘Picual’ as compared to ‘Leccino’, while there were no significant differences in rooting percentage according to cultivar, when averaged across year. The overall less successful propagation of ‘Leccino’ compared to the ‘Picual’ is not entirely in alignment with the literature. Ahmed et al.’s 2002 study of ‘Leccino’ propagation in Pakistan found that a spring sticking date was associated with the highest root number, 13.4 on average, while the spring date in our study was consistently associated with lower root numbers for ‘Leccino’, though there are no other seasons for comparison. Fabbri et al. (2004) describes ‘Leccino’ as having a high (66%-100%) rooting capacity, while ‘Picual’ is described as having a medium (33%-66%) rooting ability, and a 2013 study in Saudi Arabia found even lower rooting percentages of 1.5%-17% for ‘Picual’ when rooted with 4000ppm IBA (Hecmi et al. 2013). It is possible that Fabbri et al.’s rooting capacities only refer to rooting percentage, whereas in our study, for cuttings that did successfully root, ‘Picual’ had a greater number and length of roots than ‘Leccino’ cuttings that successfully rooted. This suggests that future studies are needed to determine which response variables may be best at predicting long-term cutting survival.

The PP11 media was associated with the highest root number, lengths, and percentages, with the PP37 generally showing equally well or intermediate performance, and the coconut coir : perlite media combinations performing least well. These results are in contrast to Isfendiyaroglu et al.’s 2009 study, in which a 1 peat : 1 perlite mix showed a decreased root number and length, compared to mixes such as a 1 perlite : 1 vermiculite media which showed higher root numbers and lengths, and rockwool media yielded the highest rooting percentage. In further contrast, Denaxa et al. (2011) demonstrated an organic media working better than 1 peat : 1 perlite. However, the greater success with 1 peat : 1 perlite media is consistent with a preliminary trial conducted at NWREC in 2017-2018, where this media was associated with higher root numbers and root length for ‘Grignan’, ‘Maurino’, and ‘Frantoio’, compared to a 100% perlite media (data not shown).

A cultivar-media interaction at the grower site suggests that certain cultivars may be more sensitive to media choice. In the 2020 trial in Dayton, ‘Leccino’ showed a root length of 3 cm and a rooting percentage of 19% when propagated with the CP37 media, with other treatment combinations, for both ‘Leccino’ and ‘Picual’ showing much higher numbers and percentages, respectively. The combination of coconut coir and perlite at that ratio may have significantly different water holding and drainage capacities, which may impact cultivars differently. In the media trial, media treatments did not show equal rates of drying, leading to additional water to be supplied, which in turn may have been excessive for some media treatments.

*2020 Compilation Trial.* This single year trial found higher root numbers, lengths, and percentages at the Aurora site, with the ‘Picual’ cultivar, and with the 2D hormone. The Aurora site in particular showed higher numbers for ‘Picual’ with either hormone, or 2D with either cultivar, and ‘Leccino’ with 3H associated with the lowest numbers. These findings are in partial agreement with part 1 of our study which found higher root length and percentage at the Aurora site compared to Dayton for propagated ‘Arbequina’ averaged across 2018 and 20219, multiple seasons, and four rooting hormone treatments. This may have to do with more consistent water management at the Aurora site, preventing both oversaturation and drying out of the media. The 2019 and 2020 Cultivar Rooting Ability and Media Trial with ‘Picual’ and ‘Leccino’ showed mixed results for the two different sites, with higher root numbers and percentages at Dayton in 2019, and no differences based on site in 2020. In this year, the cuttings at the Aurora site were among those that were lost during a power outage and had to be recollected and repropagated at a slightly later, possibly less optimal time. It is possible that if the initial cuttings from the earlier date had survived, they may have followed the same trend of superior rooting at the Aurora site.

Once again in this final trial, ‘Picual’ had higher root numbers and lengths in comparison to ‘Leccino’, which contrasts with the rooting abilities described in the literature. In our studies described here, ‘Picual’ shows a rooting percentage range from 54% (averaging results from the 2019 and 2020 Cultivar Rooting Ability and Media Trial across both sites and years) to 81% (from the 2020 Compilation Trial, with the 2D hormone averaged across both sites for the single year), and ‘Leccino’ shows a range from 25% to 75% (from the compilation trial, depending on hormone used, averaged across both sites for the single year). These results suggest that ‘Picual’ may have a higher rooting capacity, under the practices evaluated here and in Oregon’s climate, as compared to ‘Leccino.’ There are two possible explanations for this. ‘Leccino’ may have shown worse rooting in Oregon’s climate with the range of management practices used in the study, and conversely, ‘Picual’ rooting may have been improved by the management practices used. It is also possible, but less likely that the season chosen led to lower rooting percentages for ‘Leccino’, as other studies have shown spring to be an optimal season for propagating this cultivar (Ahmed et al., 2002). Ultimately, both cultivars trialed here were able to achieve rooting percentages in the high range, if propagated under optimal conditions.

**Conclusion**

These on-farm studies demonstrate successful propagation of multiple cultivars of interest in Oregon. Some cultivars showed high rooting under conditions similar to those described in the literature, while others showed higher or lower rooting success than what has been found in other studies.

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Table 3.5. Effect of year, cultivar, and rooting substrate on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Leccino' and 'Picual' olive cuttings grown for 103 days (2019) or 95 days (2020) in a heated greenhouse, at the North Willamette Research and Extension Center in Aurora, OR, Spring 2019 and 2020 (n = 16).

| Treatments | No. of Primary Roots | Total Root Length (cm) | | | | Rooting Percentage (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Substrate**[z] | | | | **Substrate** | | | |
| **Year** | | PP11 | PP37 | CP11 | CP37 | PP11 | PP37 | CP11 | CP37 |
| 2019 | 3 | 22 a[y] | 29 ab | 2 b | 11 ab | 50 a | 66 a | 06 b | 38 ab |
| 2020 | 4 | 36 a | 17 ab | 14 ab | 11 ab | 69 a | 50 a | 59 a | 38 ab |
| **Cultivar** | | | | | | | | | |
| Leccino | 3 b | 16 | | | | 50 | | | |
| Picual | 5 a | 20 | | | | 44 | | | |
| **Substrate** | | | | | | | | | |
| 1 Peat : 1 Perlite (PP11) | 6 a | 29 | | | | 59 | | | |
| 3 Peat : 7 Perlite (PP37) | 4 ab | 23 | | | | 58 | | | |
| 1 Coir : 1 Perlite (CP11) | 3 b | 8 | | | | 33 | | | |
| 3 Coir : 7 Perlite (CP37) | 2 b | 11 | | | | 38 | | | |
| **Significance**[x] | | | | | | | | | |
| *Year(Y)* | ns | ns | | | | 0.0176 | | | |
| *Cultivar(C)* | 0.0102 | ns | | | | ns | | | |
| *Substrate(S)* | 0.0019 | <.0001 | | | | 0.0013 | | | |
| *Y x C* | ns | ns | | | | ns | | | |
| *Y x S* | ns | 0.0230 | | | | 0.0004 | | | |
| *C x S* | ns | ns | | | | ns | | | |
| *Y x C x S* | ns | ns | | | | ns | | | |

[z]Substrate ratios are by volume.
[y]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.6. Effect of year, cultivar, and rooting substrate on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Leccino' and 'Picual' olive cuttings grown for 116 days (2019) and 95 days (2020) in a heated greenhouse at the grower collaborator site in Dayton, OR, Spring 2019 and 2020 (n = 16).

| Treatments | No. of Primary Roots | Total Root Length (cm) | | Rooting Percentage (%) |
|---|---|---|---|---|
| | | **Cultivar** | | |
| **Year** | | Leccino | Picual | |
| 2019 | 5 | 16 b[z] | 28 a | 68 a |
| 2020 | 4 | 19 b | 19 ab | 52 b |
| **Cultivar** | | | | |
| Leccino | 3 b | 18 | | 56 |
| Picual | 6 a | 24 | | 64 |
| | | **Cultivar** | | |
| **Substrate**[y] | | Leccino | Picual | |
| 1 Peat : 1 Perlite (PP11) | 6 a | 26 abc | 35 a | 7 |
| 3 Peat : 7 Perlite (PP37) | 4 ab | 25 abc | 19 abc | 63 |
| 1 Coir : 1 Perlite (CP11) | 4 ab | 14 bc | 19 ab | 59 |
| 3 Coir : 7 Perlite (CP37) | 3 b | 5 c | 21 ab | 48 |
| **Significance**[x] | | | | |
| *Year(Y)* | ns | ns | | 0.0083 |
| *Cultivar(C)* | 0.0002 | 0.0324 | | ns |
| *Substrate(S)* | 0.0362 | <.0001 | | ns |
| *Y x C* | ns | 0.0322 | | ns |
| *Y x S* | ns | ns | | ns |
| *C x S* | ns | 0.0441 | | ns |
| *Y x C x S* | ns | ns | | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]Substrate ratios are by volume.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.7. Effect of site, year, cultivar, and rooting substrate on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Leccino' and 'Picual' olive cuttings grown for 103-116 days (2019) and 95 days (2020) in a heated greenhouse at the North Willamette Research and Extension Center in Aurora, OR and the grower collaborator site in Dayton, OR, Spring 2019 and 2020 (n = 16).

| Treatments | No. of Primary Roots | Total Root Length (cm) | | Rooting Percentage (%) | |
|---|---|---|---|---|---|
| | | | | **Year** | |
| **Site** | | | | 2019 | 2020 |
| Aurora | 4 | 18 | | 40 b | 54 ab |
| Dayton | 4 | 21 | | 68 a | 52 b |
| | | **Cultivar** | | | |
| **Year** | | Leccino | Picual | | |
| 2019 | 4 | 14 b | 24 a | 54 | |
| 2020 | 4 | 19 ab | 20 ab | 53 | |
| **Cultivar** | | | | | |
| ‘Leccino’ | 3 b | 17 | | 53 | |
| ‘Picual’ | 5 a | 22 | | 54 | |
| **Substrate**[y] | | | | | |
| 1 Peat : 1 Perlite (PP11) | 6 a | 30 a | | 65 a | |
| 3 Peat : 7 Perlite (PP37) | 4 ab | 23 a | | 60 ab | |
| 1 Coir : 1 Perlite (CP11) | 3 b | 12 b | | 46 bc | |
| 3 Coir : 7 Perlite (CP37) | 3 b | 12 b | | 43 c | |
| **Significance**[x] | | | | | |
| *Site(S)* | ns | ns | | 0.0015 | |
| *Year(Y)* | ns | ns | | ns | |
| *Cultivar(C)* | <.0001 | 0.0143 | | ns | |
| *Substrate(Sb)* | <.0001 | <.0001 | | 0.0002 | |
| *S x Y* | ns | ns | | 0.0004 | |
| *S x C* | ns | ns | | ns | |
| *Y x C* | ns | 0.0365 | | ns | |
| *S x Sb* | ns | ns | | ns | |
| *Y x Sb* | ns | ns | | ns | |
| *C x Sb* | ns | ns | | ns | |
| *S x Y x C* | ns | ns | | ns | |
| *S x Y x Sb* | ns | ns | | 0.0015 | |
| *S x C x Sb* | ns | 0.0227 | | ns | |
| *Y x C x Sb* | ns | ns | | ns | |
| *S x Y x C x Sb* | ns | ns | | ns | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]Substrate ratios are by volume.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.8. Effect of cultivar and rooting hormone and concentration on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Leccino' and 'Picual' olive cuttings grown for 98 days in a heated greenhouse, at the North Willamette Research and Extension Center in Aurora, OR, Spring 2020 (n = 24).

| Treatments | No. of Primary Roots | | Total Root Length (cm) | | Rooting Percentage (%) | |
|---|---|---|---|---|---|---|
| | **Hormone**[z] | | **Hormone** | | **Hormone** | |
| **Cultivar** | 2D | 3H | 2D | 3H | 2D | 3H |
| 'Leccino' | 4 ab[y] | 1 b | 29 a | 10 b | 96 a | 29 b |
| 'Picual' | 5 a | 6 a | 28 a | 32 a | 92 a | 79 a |
| **Significance**[x] | | | | | | |
| *Cultivar(C)* | <.0001 | | 0.0157 | | 0.0022 | |
| *Hormone(H)* | ns | | ns | | <.0001 | |
| *C x H* | 0.0484 | | 0.0068 | | 0.0003 | |

[z]Hormone treatments included: 'Dip'N Grow' 2000ppm IBA + 1000ppm NAA and 'Hormex' 3000ppm IBA.
[y]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.9. Effect of cultivar and rooting hormone and concentration on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Leccino' and 'Picual' olive cuttings grown for 98 days in a heated greenhouse, the grower collaborator site in Dayton, OR, Spring 2020 (n = 24).

| Treatments | No. of Primary Roots | Total Root Length (cm) | Rooting Percentage (%) |
|---|---|---|---|
| **Cultivar** | | | |
| 'Leccino' | 1 b[z] | 8 b | 38 b |
| 'Picual' | 4 a | 22 a | 60 a |
| **Hormone**[y] | | | |
| 2D | 3 a | 20 a | 63 a |
| 3H | 1 b | 9 b | 35 b |
| **Significance**[x] | | | |
| *Cultivar(C)* | <.0001 | 0.0006 | 0.0212 |
| *Hormone(H)* | 0.0016 | 0.0053 | 0.0069 |
| *C x H* | ns | ns | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]Hormone treatments included: 'Dip'N Grow' 2000ppm IBA + 1000ppm NAA and 'Hormex' 3000ppm IBA.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.10. Effect of site, cultivar and rooting hormone and concentration on mean total number of primary roots, mean total root length (cm) including all roots longer than 5mm, and rooting percentage for propagated 'Leccino' and 'Picual' olive cuttings grown for 98 days in a heated greenhouse, at the North Willamette Research and Extension Center in Aurora, OR and the grower collaborator site in Dayton, OR, Spring 2020 (n = 24).

| Treatments | No. of Primary Roots | Total Root Length (cm) | Rooting Percentage (%) | |
|---|---|---|---|---|
| **Site** | | | | |
| Aurora | 4 a[z] | 25 a | 74 a | |
| Dayton | 2 b | 15 b | 49 b | |
| | | | **Hormone** | |
| **Cultivar** | | | 2D | 3H |
| Leccino | 2 b | 14 b | 75 a | 25 b |
| Picual | 5 a | 26 a | 81 a | 65 a |
| **Hormone**[y] | | | | |
| 2D | 4 a | 24 a | 78 | |
| 3H | 2 b | 15 b | 45 | |
| **Significance**[x] | | | | |
| *Year(Y)* | 0.0008 | 0.0006 | <.0001 | |
| *Cultivar(C)* | <.0001 | <.0001 | 0.0002 | |
| *Substrate(S)* | 0.0011 | 0.0015 | <.0001 | |
| *Y x C* | ns | ns | ns | |
| *Y x S* | ns | ns | ns | |
| *C x S* | ns | ns | 0.0067 | |
| *Y x C x S* | 0.0164 | 0.0012 | ns | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]For hormone treatments 2D = 'Dip n Grow' 2000ppm IBA + 1000ppm NAA and 3H = 'Hormex' 3000ppm IBA.
[x]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

## 4. Differences in vegetative growth and plant survival of olives during orchard establishment in Oregon


### Abstract

Olives, native to the Mediterranean, may benefit from production practices specifically adapted to orchard establishment in colder climates. This three-year, multi-site study evaluated the impact of production systems and four potentially cold-tolerant cultivars on vegetative growth and survival after transplanting in northwestern Oregon, USA. Production practices included a spring-planted field with raised beds and in-row geotextile weed mat, and a fall-planted field with cover cropped aisles, at a lower elevation site, flat ground site, and replicated at a higher elevation, sloped site. Fall plantings evaluated trees planted at 1.5 and 2.5 years of age. Cultivars included 'Amphissa', 'Ascolano', 'Frantoio', and 'Leccino'. Winter temperatures were not cold enough to test the hypothesis that trees planted at older ages and larger sizes would show increased survival compared to younger, smaller transplants. Spring-planted fields at both sites showed cultivar differences in years two and three. 'Leccino', 'Frantoio', and 'Amphissa' had increased shoot growth and trunk diameters. Trees planted at the lower elevation site in Spring 2019 had 100% survival two years post-transplant, compared to 68% survival for trees at the higher elevation site. Higher shoot numbers occurred in the fall-planted fields at NWREC, though longer shoots were measured in the NWREC spring-planted field, with Leccino', 'Frantoio', and 'Amphissa' showing increased growth. Trees planted in Spring 2019 and Spring 2020 had 99% survival at the completion of the trial compared to 91% survival for trees planted in Fall 2018 and Fall 2019 at NWREC. The impact overwintering practices and tree age and size at time of planting varied based on site and cultivar. Findings suggest that the spring-planted production system may lead to increased vegetative growth and survival rates in years with mild winters, and that 'Leccino', 'Frantoio', and 'Amphissa' show higher growth rates than 'Ascolano' in Oregon's climate.

**Introduction**

Olive production for oil in North America can be traced to an introduction by Spanish missionaries, with the establishment of orchards along the California coast and Sierra Nevada foothills, and the first commercial oil mill in the 1870s (Vossen, 2007). Olive orchards were first established in Oregon in the 2000s, with a handful of small farms and one commercial mill (Barker and Fernandez-Salvador, unpublished data). Olives are considered to be "easily adaptable" outside their native Mediterranean climate to areas with warmer temperatures, due to leaf morphology that allows trees to tolerate high temperatures and water stress, and their lack of a photoperiodic response (Lavee, 2014). In contrast, olive production in Oregon faces the risk of winter cold damage to trees, as average annual extreme temperatures can drop to -12 °C (USDA, 2020). Historically, Oregon growers have lost trees to cold damage during the establishment years, a topic not addressed by the California crop production information Oregon growers have tended to consult.

Olive tree age and size is linked to susceptibility to cold damage, with younger trees, consisting of smaller diameter limbs and trunks, at greater risk of damage at relatively higher temperatures (-6 °C) than older, larger trees with thicker diameter wood (-9 °C) (Sibbett and Osgood, 2015). However, California production guidelines suggest planting trees between 14 and 21 months after propagation (Sibbett and Osgood, 2015). While this works for orchard establishment in California, where in super-high-density production systems even low vigor cultivars begin fruiting in their second year and reach full bearing in year four or five (Vossen, 2007), orchard establishment is expected to take longer in Oregon's climate, due to dieback from winter cold damage, and shorter growing seasons.

An alternative orchard establishment technique is to plant older, larger trees, with the goal of preventing winter cold damage and improving transplant survival rates. There are few horticultural experiments studying the effect of tree age at planting. Moreno-Alías et al. evaluated different transplant ages for olives, though this was limited to a range of 22-38 weeks post-germination for seedlings (2010). Transplanting trees much older than this requires one or more years of growth in protective structures such as greenhouses or passive tunnels. This practice will be referred to as up-potting, overwintering and transplanting, or up-potting in short, and is fairly common in other cropping systems, such as citrus (Yano et al., 2018). As far as we are aware, there have been no studies on this topic in olives; while Preziosi and Tini (1990) evaluated the effect of pot size on young olive growth in protective structures, they did not measure the growth of these same trees in the field, post-transplant.

Additionally, certain production system practices may encourage more rapid vegetative growth during establishment seasons and mitigate winter cold damage to young trees. These practices include choice of planting season, row management and bed-shaping, and weed prevention. Cultivar choice can also play a role in orchard establishment and prevention of cold damage. Different cultivars may have a faster growth rate, and increased tolerance to cold damage. While there are many cultivars considered to be “cold tolerant” in the Mediterranean or warmer, non-native production regions (Vossen, 2007) for the purposes of this study, cold-tolerant refers to cultivars that may be more resilient to lower temperatures, rather than avoiding damage altogether.

The objectives of this study were: 1) determine optimal production system practices including planting season and up-potting, and 2) evaluate four potentially cold-tolerant cultivars for differential vegetative growth and survival during the first three years (2018-2020) of olive orchard establishment in Oregon.

**Materials and methods**

*Plant material.* Overwintering structures were located at the Oregon State University North Willamette Research and Extension Center (NWREC) in Aurora, OR (45°16'49.65"N, 122°45'1.94"W), near one of the two field sites. In Mar. 2018, 2019, and 2020, 320 olive trees were received from Santa Cruz Nursery, CA. Shipments contained 80 each of the four cultivars: ‘Amphissa’ (Greek; Chartzoulakis et al., 2002) ‘Ascolano’ (Italian; Vossen, 2007), ‘Frantoio’, and ‘Leccino’ (both Italian/specifically Tuscan; Vossen, 2007), in 7.6 cm x 7.6 cm x 10.2 cm pots. Depending on the year, plants ranged from six to 18 months old. Each year, the oldest/largest plants were designated for spring planting, to reduce variation between cultivars and allow smaller plants time to catch up before fall-planting. All plants were transplanted into 2.8L (0.74 gallon, commonly referred to as 1 gallon/1 “deep”) containers, using conventional potting media (33% fine bark, 33% peat moss, and 33% pumice; 5F soil blend, ProGro Mixes and Materials; Sherwood, OR, USA).

*Up-potting and overwintering.* From April/May through October, plants were kept in a retractable roof greenhouse (Cravo Equipment Ltd.; Brantford, Ontario, CA) on site, with automated sprinkler irrigation, adjusted weekly to account for changes in weather and evapotranspiration. A portion of trees were planted in the fields each spring and fall, with the remainder kept overwinter. In October each year, these plants were moved to a 22 m x 3 m double-walled insulated passive hoop with automated sprinkler irrigation, box fans for airflow, and emergency backup propane heaters for nights when temperatures were forecast to drop below -4.4 °C, a few degrees warmer than the temperature threshold for tissue damage. This structure was chosen specifically to trial a low-cost technique applicable to local growers. A temperature and relative humidity logger (DROP D2, Kestrel Meters; Boothwyn, PA, USA, or HOBO MX2301; Onset Computer Corp.; Bourne, MA, USA) was used to monitor hourly greenhouse temperatures and relative humidity. In November/December, these trees were moved into larger pots or “up-potted”, with plants received the current year and in 2.8 L (0.74 gal/1 deep) pots transplanted into 9.7 L (2.56 gal/3 deep). Plants received conventional controlled-release granular fertilizer (16N–2.2P–8.3K, Polyon, Harrell’s LLC; Lakeland, FL, USA) twice per year; once in the spring, with 2.8 L plants given 14.3 g and 9.7 L given 28.3 g, and again in the fall upon up-potting, with all plants moved into 9.7 L pots receiving an additional 14.3 g. Flowers were hand-removed each spring.

*Site preparation.* This study was conducted at two sites, each containing two fields equating to the two production system treatments of spring and fall planting. The NWREC field site is at 43 m elevation, with mean annual air temperature of 11-12 °C and mean annual precipitation of 102-127 cm (see latitude and longitude in Plant material above). Soil is a Willamette silt loam (Fine-silty, mixed, mesic Pachic Ultic Argixerolls) (Soil Survey Staff, n.d.), with a pH of 5.95 for the spring-planted field and 5.90 for the fall-planted field prior to planting. The Oregon State University Woodhall III Vineyard (Woodhall) field site is at Monroe OR (44° 20' 22.5816"N, 123° 24' 28.6164"W), at an average 190 m elevation, with mean annual air temperature of 10-12 °C and mean annual precipitation of 102-152 cm. Soil is predominantly a Bellpine-Jory complex (Fine, mixed, active, mesic Xeric Haplohumults), with 0.12 ha at the northern end of the fall-planted field a Jory silty clay loam (Fine, mixed, active, mesic Xeric Palehumults), and 0.2 ha at the southern end of the spring-planted field a Willakenzie loam (Fine-loamy, mixed, active, mesic Ultic Haploxeralfs) (Soil Survey Staff, n.d.). The soil pH was 5.75 for the spring-planted field, and 5.75 for the fall-planted field, prior to planting. Both sites were previously fallow.

Soil pH in all four fields was at the low end of the recommended range (5.5-8.5, Vossen and Ravetti, 2019), requiring amendment with agricultural lime (pelletized lime, Pro-Pell-It, Marion Ag Service Inc; St. Paul, OR, USA) to raise the pH. At Woodhall, site preparation utilized a tiller, a double pass with spader, and a harrow and roller to till the soil and incorporate lime at a rate of 3.3 metric tons/ha in Oct. 2017. At NWREC, site preparation utilized a chisel and disc tiller to till soil and incorporate lime at a rate of 2.2 metric tons/ha in May 2018. The spring-planted field at NWREC was 0.15 ha and consisted of thirteen 37 m long rows, while the equivalent at Woodhall was 0.17 ha and consisted of seven 79 m long rows with a 5 m elevation change. Spring-planted fields at both sites included 60.1 cm raised beds, woven geotextile polypropylene weed mat (Baycor, TenCate Geosynthetics; Pendergrass, GA, USA), and drip irrigation with pressure compensated emitters (Woodpecker JR PC, 3.8 L/hr flow rate; Netafim USA; Fresno, CA, USA). Aisles were planted with perennial ryegrass (*Lolium perenne*) and mowed as needed. The fall-planted field at NWREC was 0.43 ha with thirteen 110 m long rows, while the equivalent at Woodhall was 0.47 ha with seven 219 m long rows with a 35 m elevation change. Tree rows at both fall-planted sites were on flat (non-raised) beds, with 0.6 x 0.6 m (bare soil cleared squares centered on tree trunks, native vegetation in-row, and a rotational cover crop in the inter-row. Cover crop rotations consisted of crimson clover (*Trifolium incarnatum*), oats (*Avena sativa*), and oats and hairy vetch (*Vicia villosa*).

*Crop establishment.* On 2 and 3 July 2018, 13 and 22 May 2019, and 21 and 28 May 2020, ten 2.8 L trees each of the four cultivars ('Amphissa', 'Ascolano', 'Frantoio', 'Leccino') were transplanted into the spring-planted fields at each site. On 17 and 22 Oct. 2018, 17 and 22 Oct. 2019, and 13 and 20 Oct. 2020, ten 2.8L trees each of the four cultivars listed above were transplanted in the fall-planted fields. Additionally, in Oct. 2019, ten 9.7 L plants of each cultivar, having been up-potted and overwintered in the passive hoop house for one winter, were transplanted into the fall-planted fields at each site. Trees were planted at 3 m spacing, and watered in at the time of planting. Temperature and relative humidity loggers (HOBO MX2301; Onset Computer Corp.; Bourne, MA, USA) were installed at both sites in Dec. 2018, to monitor hourly environmental conditions throughout the winter. Prior to this, temperature data from AgriMet (USBR, 2021) Aurora, OR and Corvallis, OR stations were used to approximate for NWREC and Woodhall data, respectively.

*Crop management.* Fields were fertilized July-Sept. 2018 using 5N–0.4P–0.8K organic fish emulsion fertilizer (Alaska Fish Fertilizer, Central Garden & Pet Co., Lilly Miller Brands; Atlanta, GA, USA); June-Aug. 2019 using organic composted food waste fertilizer 3N–0.4P–0.8K (Nature's Source Organic, Ball DPF LLC; Sherman, TX, USA) in 2019; and using a split application in 2020, with 50% of the nitrogen applied as 12N-0P-0K organic feather meal (Pro-Pell-It, Marion Ag Service Inc; St. Paul, OR, USA ) applied in Apr. 2020, and the remaining 50% June-July using the same liquid fertilizer as in 2019 (see Table 4.1 for total nitrogen applied). Liquid fertilizer was applied using a hand-sprayer or via the drip irrigation system. Soil and tissue testing were conducted yearly by Brookside Laboratories, Inc. (New Bremen, OH, USA). In Mar. 2020, Woodhall showed a pH of 5.2 and 5.8 respectively for spring and fall-planted fields, and so lime (pelletized lime, Pro-Pell-It, Marion Ag Service Inc; St. Paul, OR, USA) was applied Apr. 2020 at a rate of 0.56 metric tons/ha and 2.24 metric tons/ha, respectively.

Spring-planted fields were irrigated July-Sept. 2018, and June-Sept. 2019 and 2020. Trees were given approximately 125-625 ml water per tree per day, adjusted based on evapotranspiration and previous week precipitation. Fall-planted fields were initially intended to be dry-farmed; however severe water stress in early spring 2019 and advice from project collaborators suggested the addition of temporary irrigation. Temporary establishment drip irrigation was installed at NWREC in May 2019, and due to site limitations, delayed until July 2020 at Woodhall. Throughout the 2019 growing season, and prior to the installation in 2020, Woodhall fall-planted trees were watered and fertilized by hand, with trees receiving 3.79 L of water per week, and fertility equivalent to the fertigated fields. This application method may have led to inconsistencies and so NWREC and Woodhall fall-planted field data was analyzed separately, and Woodhall spring and fall-planted fields were analyzed separately.

Plots in all fields were managed similarly in terms of weeding and groundcover maintenance, pest control, and pruning. Perennial ryegrass aisles were flail mowed twice monthly or as needed through the spring and summer for spring-planted fields. Weed mat openings near the trunk were kept weed-free. Weed-free squares around trunks of fall-planted trees were maintained as described above, and aisles were mowed with a push or flail mower, with occasional string trimmer mowing through the spring and summer as needed. In 2020, flowers and developing fruit were removed from fall-planted trees, which showed less vigor than spring-planted trees that were allowed to develop fruit. Yield data will not be shown or discussed here.

*Data collection.* Vegetative growth data included number of shoots for all shoots over 5 cm, length of longest shoot, and trunk diameter at 10 cm from soil surface (see Fig. 4.1). For shoot number, fully dead shoots were not included, but shoots with only partial die-back were counted. Longest shoot excluded the trunk, except for 2.8 L pot sized plants with no additional shoots. In Spring 2020, student error led to no “longest shoot” recorded for some trees 2.8 L plants, and so these were approximated as zero. Length was measured from the point where the primary shoot emerged from the trunk, until the apex of any secondary or tertiary shoot extending furthest away from the origin at the trunk and was recorded in centimeters. For trees with multiple trunks, the greatest trunk diameter was recorded in millimeters, using digital or dial calipers. Survival was also recorded for each plant at the time of data collection. Trees that had died back down to the base of the trunk and were resprouting were counted as dead and not included in further data collection. Data was collected on the following dates: 10 and 17 July 2018, 31 Oct. through 16 Nov. 2018, 20 May through 4 June 2019, 5 and 12 Nov. 2019, and 3-11 June 2020, and 27 Oct. through 6 Nov. 2020.

*Data analysis.* Data for shoot number, length of longest shoot, and trunk diameter were used to calculate difference in response variables over one, two, or three growing seasons. Growing seasons equated to 6 months for spring-planted trees, with differences calculated as fall minus spring measurement. Growing season equated to 12 months for fall-planted trees, with differences calculated as fall measurement one, two, or three years since planting minus fall measurement from the year prior. This yielded final response variables of difference in shoot number, difference in length of longest shoot, and difference in trunk diameter. In some instances, the calculated difference was a negative number, indicating dieback over the growing season, and in these cases, the measurement was considered as zero.

The experiment was a randomized complete block with split plot design and ten replicates, blocked by production system, split with cultivar as the main plot and planting age as the subplot, and individual trees as the experimental unit. Due to the loss of some trees leading to missing complete replicates for some cultivars, replication was reduced at random from other cultivars to retain a balanced design for analysis. This reduced the replicate number to between 5 and 9 based on the variation in mortality based on the site, planting season, and planting year. There were four different analyses conducted. The first analysis was a site comparison of spring-planted fields, which utilized a split-plot 3-factor randomized complete block design with site as a factor (two levels), planting year as a factor (three levels), and cultivar as a factor (four levels) with five replicates at each site, equating to 120 experimental units. The second analysis compared spring-planted production systems and fall planted systems at NWREC, and used a split-plot 3-factor randomized complete block design with production system as a factor (two levels), planting year as a factor (two levels), and cultivar as a factor (four levels) with seven replicates, resulting in 112 experimental units. The third analysis was a site-by-site comparison of age/size at planting, consisting of a split-plot 2-factor randomized complete block design with age/size at planting as a factor (two levels) and cultivar as a factor (four levels), with nine replicates and 72 experimental units at NWREC and six replicates and 48 experimental units at Woodhall. The final analysis was a site-by-site comparison of fall-planted production systems, and used a split-plot 2-factor randomized complete block design with planting year as a factor (two levels) and cultivar as a factor (four levels), with seven replicates and 56 experimental units at NWREC and six replicates and 48 experimental units at Woodhall. Survival percentage was calculated as number of trees alive at the final Fall 2020 data collection date, compared to number of trees planted, with planting years analyzed separately, and included the full ten replicates.

Data were analyzed using R software (version 3.5.2; R Foundation for Statistical Computing, Vienna, Austria). Treatment effects were examined by analysis of variance using linear models (R package lm) for difference in shoot number, difference in shoot length, and difference in trunk diameter, and generalized linear mixed models (GLMM) (R package lmer) for survival percentage, both of which assume errors are normally distributed. For significant treatment effects, treatment differences were determined using the Tukey-Kramer honestly significant difference test (at $P \leq 0.05$).

**Results and discussion**

Data collection methods were based on Porras-Soriano et al. which included shoot number, “maximum length of stem”, and stem (trunk) diameter at 5 cm from soil for measuring vegetative growth of young olive trees (2006 and 2009). Trunk diameter was chosen rather than tree height due to this being a more consistent measurement between trees with different growth habits, which was likely to occur with four different cultivars (Aragüés, Guillén & Royo, 2010). The decision to calculate seasonal or yearly differences in growth was based on methods used in Aragüés et al. (2004 and 2010).

*Site comparison of spring-planted tree vegetative growth, first year: comparison of 2018, 2019, and 2020 planting years.* Trees at NWREC had a greater difference in trunk diameter compared to Woodhall (Table 4.2). Differences in shoot number, shoot length, and trunk diameter varied depending on planting year and cultivar. 2019 ‘Leccino’ had the highest shoot number, followed by 2019 ‘Frantoio’, which was not different than 2018 ‘Amphissa’, ‘Frantoio’, and ‘Leccino’, 2019

‘Ascolano’ and ‘Amphissa’, and 2020 ‘Frantoio’ and ‘Leccino’. Lowest shoot numbers were seen for 2020 ‘Amphissa’, ‘Ascolano’, and 2018 ‘Ascolano’. 2019 ‘Leccino’ also had the greatest shoot length and trunk diameter, though it was not different than all other cultivars for 2019 and 2018 ‘Leccino’ for shoot length, and not different than 2018 and 2019 ‘Amphissa’, 2019 and 2020 ‘Frantoio’, and 2020 ‘Leccino’ for trunk diameter. 2020 ‘Amphissa’ had the smallest increase in shoot length and trunk diameter.

*Site comparison of spring-planted tree vegetative growth, second year: comparison of 2018, 2019 planting years.* Trees planted at NWREC had a higher shoot number at 58, compared to 41 for Woodhall (Table 4.3). The 2018 planting year was associated with an increased shoot length but a decreased trunk diameter compared to the 2019 planting year. ‘Amphissa’ had an increased shoot length compared to ‘Ascolano’ with the shortest length, and ‘Frantoio’ and ‘Leccino’ not different from either the high or low values. ‘Leccino’ had the greatest trunk diameter, and ‘Ascolano’ had the least, with ‘Amphissa’ and ‘Frantoio’ not different than the other two cultivars.

When analyzing two cumulative years of growth, NWREC trees had a higher number of shoots compared to Woodhall (Table 4.4). Across both years, 2019-planted trees had higher shoot numbers and shoot length, and larger trunk diameters. ‘Leccino’ and ‘Frantoio’ had the greatest shoot numbers, with ‘Amphissa’ and ‘Ascolano’ lower but not different than ‘Frantoio’. ‘Frantoio’, ‘Amphissa’, and ‘Leccino’ had the greatest shoot length, though ‘Leccino’ was not different from ‘Ascolano’. Similar to shoot length, ‘Leccino’ and ‘Amphissa’ had the greatest trunk diameter, with ‘Frantoio’ less than ‘Leccino’ but not different from ‘Amphissa’, and ‘Ascolano’ having the smallest trunk diameter, but not different from ‘Frantoio’. There was an interaction between site, planting year, and cultivar for longest shoot.

*Site comparison of spring-planted tree vegetative growth, three years: 2018 planting year.* Trees planted at NWREC had nearly 100 more shoots than those at Woodhall (Table 4.5). Different cultivars showed variation in shoot number and shoot length depending on site. NWREC ‘Leccino’ trees had the greatest shoot number, and Woodhall ‘Amphissa’, ‘Ascolano’, and ‘Leccino’ had the lowest shoot numbers, with all other cultivars at each site not different than the highest and lowest values. Conversely, Woodhall 'Leccino' had the longest shoot, which was not different from all other cultivars at each site except for NWREC 'Ascolano', which had the shortest shoot length, though it was not different from all other cultivars except for the highest value. 'Leccino' had the greatest increase in trunk diameter while 'Ascolano' had the lowest trunk diameter, and 'Amphissa' and 'Frantoio' were not different from any other cultivar.

*Site comparison of spring-planted trees survival.* Two-year old trees planted in Spring 2019 showed 100% survival at NWREC as of Fall 2020, compared to 68% at Woodhall (as shown in Fig. 4.2). There were no differences between either site or cultivar for survival rates for one-year-old trees planted Spring 2020, or three-year-old trees planted Spring 2018 (data not shown).

Differences in growth based on site may be related to temperature variations. NWREC tended to have lower temperatures than Woodhall in 2018 and 2020, and higher temperatures in 2019 (as shown in Figs. 4.3a-c), while both the NWREC site and the 2019 planting year were often associated with increased vegetative growth. This may be related to heat stress occurring at the Woodhall site in 2018 and 2020, with other site conditions at NWREC mitigating the same heat stress at that site in 2019. Other major site differences include the elevation change at Woodhall, and soil types, though the majority of the spring-planted field at Woodhall is a loam, which is comparable to the silt loam at NWREC. Alternatively, the difference in survival may be due to a combination of tree health at the time of planting and site differences. Many of the trees planted at Woodhall in 2019 showed signs of root rot, which likely developed in the greenhouse due to overwatering, and may have been exacerbated by the sloped ground and resultant more shallow soils impeding soil drainage at Woodhall (Vossen and Ravetti, 2019). This is comparable to the risks Sánchez-Hernández et al., describe as part of the transplant process, including pathogens, pest damage, and soil drainage issues (1998).

Trees planted in 2019 often showed higher growth rates compared to the trees planted 2018 and 2020. This is not likely due to initial tree size, as the 2019 batch of trees were slightly younger on average than 2018 trees, with a range of 6-18 months of age at receipt, vs. 18 months for 2018 trees, suggesting differences are not due to planting stock differences. Additionally, while 2019 trees received nearly three times the amount of N per tree in their first growing season (see Table 4.1; this was due to the need to increase total N fertilizer applications in the second year of the trial to account for both 1.5- and 2.5-year-old trees in the same field), this equated to 22 g N/tree, which falls within the low N range Othman and Leskovar's 2019 study demonstrated to be optimal for root and shoot growth of newly established 'Arbequina' olives. Rather, the 2019 trees were planted earlier in the season than the 2018 trees, which were planted in July due to a delay in field preparation. This is in line with the recommendation of March/April (spring) plantings for olives in California, as trees planted in the summer show poor growth the first year (Sibbett and Osgood, 2015).

When looking at the impact of cultivar on growth, 'Leccino', 'Frantoio', and 'Amphissa' more often showed higher growth rates than 'Ascolano'. This points to potential cultivar differences in vigor and vegetative growth characteristics. 'Leccino' and 'Frantoio' have often been cited as having "medium or high vigor" (Vivaldi et al., 2015), marked by an increased dry weight of pruned wood for 'Frantoio' (D'Andria et al., 2009), and high canopy volumes, trunk cross-sectional area, and weight of pruned wood for both cultivars (Farinelli and Tombesi, 2015). A study on olive establishment in Hawaii, USA, found that spring-planted 'Frantoio' and 'Leccino' were among the cultivars with the largest trunk diameter 22 months after transplanting, with 'Leccino' having a greater height than 'Frantoio' (Miyasaka and Hamasaki, 2016). There are few studies that have included 'Amphissa', with the majority are focused on its response to saline irrigation water (Chartzoulakis et al., 2002; Koubouris et al., 20015; and Loupassaki et al., 2002), though in control (non-saline-treated plants), 'Amphissis' as it is also referred to showed the highest total dry weight and leaf area compared to other Greek cultivars (Chartzoulakis et al., 2002). In contrast, a study of December-planted trees found that among ten cultivars, five-year-old 'Ascolano' had either the highest or among the highest truck cross sectional area (Aïachi Mezghania et al., 2012), while in our study this cultivar showed the least change in trunk diameter across three years.

*NWREC comparison of spring- vs. fall-planting vegetative growth, first year: 2018/2019 and 2019/2020 planting years.* Trees planted in Fall 2018/Spring 2019 had a greater increase in shoot number and trunk diameter (Table 4.6) compared to trees planted in Fall 2019/Spring 2020). Fall-planted trees had greater shoot numbers and trunk diameter compared to spring-planted trees. ‘Leccino’ had the greatest shoot number, ‘Amphissa’ had the lowest, while ‘Frantoio’ and ‘Ascolano’ shoot numbers were not different from ‘Leccino’ or ‘Amphissa’. The impact of planting year on shoot length varied depending on production system, with 2018/2019 spring-planted trees having twice the shoot length of 2019/2020 spring-planted trees, and four times the shoot length of both fall-planted sets of trees. Spring-planted ‘Leccino’, ‘Frantoio’, and ‘Ascolano’ had the greatest shoot length, and were not different from spring-planted ‘Amphissa’, which itself was not different from fall-planted ‘Amphissa’ and ‘Ascolano’, while fall-planted ‘Frantoio’ and ‘Leccino’ had the shortest shoot lengths. Shoot length and trunk diameter were impacted by the interaction of planting year and cultivar. All cultivars planted in 2018/2019 as well as 2019/2020 ‘Ascolano’ had greater shoot lengths, compared to 2019/2020 ‘Amphissa’ and ‘Frantoio’, while 2019/2020 ‘Leccino’ was not different from the highest and lowest values. 2018/2019 ‘Amphissa’, ‘Frantoio’, and ‘Leccino’ had the greatest trunk diameters, with 2018/2019 ‘Ascolano’ and 2019/2020 ‘Amphissa’ having the smallest trunk diameters, and 2019/2020 ‘Ascolano’, ‘Frantoio’, and ‘Leccino’ not different from the lowest values.

*NWREC comparison of spring- vs. fall-planting vegetative growth, second year: 2018/2019 planting year.* In their second growth season (encompassing 12 months for fall-planted and 6 months for spring-planted trees), fall-planted trees had a greater trunk diameter compared to spring-planted trees (Table 4.7). The effect of cultivar on shoot number and shoot length depended upon the production system, with fall-planted ‘Frantoio’ and ‘Leccino’ having greater shoot numbers than fall-planted ‘Ascolano’ and ‘Amphissa’ and all spring-planted trees. In contrast, spring-planted ‘Frantoio’ and ‘Amphissa’ had the greatest shoot lengths, though ‘Ascolano’ planted in either season was not different from ‘Amphissa’. ‘Frantoio’, ‘Leccino’, and ‘Amphissa’ had the greatest trunk diameters, all higher than ‘Ascolano’.

Across two growing seasons, 'Frantoio' and 'Leccino' had the greatest shoot numbers at 216 and 204 respectively, with 'Amphissa' at 102 and 'Ascolano' at 141 half and nearly half the shoot number of other cultivars, respectively (Table 4.8). The interaction between cultivar and production system persisted throughout two growing seasons, with spring-planted 'Leccino', 'Amphissa', and 'Leccino' having the greatest shoot lengths, spring-planted 'Ascolano' not different from spring-planted 'Amphissa' and 'Leccino', and all fall-planted cultivars with the shortest lengths, ranging from 13-21 cm. Similar to year two, 'Frantoio', 'Leccino', and 'Amphissa' had the greatest trunk diameters, all higher than 'Ascolano' which was nearly half that of 'Leccino'.

*NWREC spring vs. fall planting survival.* Spring-planted trees at NWREC showed higher survival rates as of Fall 2020 at 99%, compared to fall-planted trees at 91% (as shown in Fig. 4.4). This includes trees planted during the 2018/2019 and 2019/2020 seasons, with no difference between the years.

Spring-planted trees may have fewer, longer shoots due to the type of winter damage incurred by fall-planted trees. While temperatures did not drop low enough during any part of the experiment for trees to experience mortality, observations suggested that fall-planting was associated with higher levels of tip die-back than with spring-planting. This die-back is comparable to the tip-heading pruning evaluated in Albarracín et al. (2019), which encouraged development of new shoots on base branches in five-year-old 'Arbequina' trees. The higher survival rates in spring-planted trees aligns with the recommendation of spring rather than summer or fall plantings for California olives (Sibbett and Osgood, 2015).

*NWREC comparison of age at fall-planting vegetative growth.* Note: This analysis compared trees that were part of the same shipment, with half of the trees planted at 1.5 years of age in Fall 2018, and half of the trees planted at 2.5 years of age in Fall 2019, in terms of difference in growth variables over their second year in the experiment (Fall 2019-Fall 2020), equating to the second year in the field for the 1.5-year-old trees, and the first year in the field for the 2.5-year-old trees. This was the only analysis that could be conducted for these trees, as measurements were not taken in the greenhouse, and so the first year in the experiment could not be analyzed.

The impact of age at planting on shoot number depended upon cultivar. 'Frantoio' and 'Leccino' had higher shoot numbers if planted as 1.5-year-old trees, followed by 'Ascolano' planted as 2.5-year-old trees, with 2.5-year-old 'Ascolano' not different than every other cultivar-age combination, excluding 1.5-year-old 'Leccino' (Table 4.9). Trees planted at 1.5 years had larger trunk diameters than those planted at 2.5 years, while all cultivars had greater trunk diameters compared to 'Ascolano'.

*NWREC age at fall-planting survival.* There was no difference in survival rate for trees planted at 1.5 years of age, compared to trees planted at 2.5 years, with each averaging 95% survival as of Fall 2020 (as shown in Fig. 4.5).

*Woodhall comparison of age at fall-planting vegetative growth.* See note at NWREC age at fall-planting for more details on this analysis. Trees planted at 1.5 years of age had nearly twice the number of shoots compared to those planted at 2.5 years of age (Table 4.10). 'Frantoio' and 'Ascolano' had the greatest shoot numbers, with 'Ascolano' not different from 'Amphissa' and 'Leccino'. Trees planted at the younger age had eight times the shoot length of those planted at 2.5 years of age. 'Frantoio', 'Leccino', and 'Amphissa' had the greatest trunk diameters, with 'Ascolano' not different from 'Leccino' and 'Amphissa'.

*Woodhall age at fall-planting survival.* Trees planted at 1.5 years of age had lower survival rates as of Fall 2020, compared to trees planted at 2.5 years of age (as shown in Fig. 4.6).

The possibility that potted trees may have experienced growth suppression may be compared with Preziosi and Tini's evaluation of optimal pot sizing for growing rooted 'Frantoio' cuttings in a nursery setting for two years (1990). They found that use of 2.7 L (0.7 gal) sized pots in year one followed by 6.5 L (1.7 gal) pots in year two were associated with increased height in the first year, and plant heights in 2.7 L pots were not significantly different from those occurring with larger pots in year two, though trunk diameter did show increases as larger pots were used, suggesting that, costs aside, use of pots larger than 2.7 and 6.5 L respectively may be preferable if trying to achieve high rates of growth in the greenhouse (Preziosi and Tini, 1990). This is further supported by Poorter et al.'s meta-analysis of the effect of pot size in plant biology across multiple disciplines, which found that doubling the size of the pot is associated with a nearly 50% increase in plant biomass (2012).

Survival rates at may be due irrigation differences, with 1.5-year-old trees at Woodhall watered less frequently and by hand during their first year in the field, compared to the frequent automated irrigation 2.5-year-old trees received in the greenhouse during their first year. This difference would be less pronounced for NWREC trees planted at 1.5 years old, as that field had temporary establishment irrigation installed in 2019 compared to 2020 for Woodhall. To our knowledge there are no studies on the impact of planting age and size in olives, other than Moreno-Alías et al.'s study focusing on a narrow range of young planting ages (2010). In a review of research on transplant size on landscape tree establishment, Watson's assumption is that transplanted trees will have been dug up from the nursery without their entire root ball, rather than grown in pots, and therefore older, larger trees may be at a disadvantage in terms of needing to regrow a larger root mass than younger, smaller trees (2005). This is not the case in our study, where trees are transplanted with intact root balls. A 2009 study on transplanting native woody species in the Czech Republic found that smaller size transplants, classified as those between 1-1.5 m tall, grew more than medium and large size transplants, though there were differences among multiple species (Dostálek et al.), in contrast to a 2019 study of hardwood species in Canada, which found varied survival rates among 3- and 6-year-old transplants of red oak (Quercus rubra) and sugar maple (Acer saccharum Marsh.) though for both species, older trees showed increased height and diameter at breast height (Rivest and Cogliastro, 2019). These studies point to the complexity of transplanting larger trees, and the need for increased research on the benefits and disadvantages of overwintering and transplanting older, larger trees in their non-native growing region.

When looking at cultivar, at both sites 'Amphissa', 'Frantoio', and 'Leccino' had greater trunk diameters than 'Ascolano' regardless of age/size at time of planting. This reflects the results seen in the site comparison of spring-planted trees and comparison of spring planting and fall planting at NWREC, suggesting that this difference in trunk diameters by cultivar may be a more inherent trait that is not as easily impacted by crop management practices.

*NWREC comparison of fall-planted trees vegetative growth, first year: comparison of 2018, 2019 planting years.* The impact of cultivar on shoot length varied based on planting year. 2019 'Ascolana' had the greatest shoot length, which was not different than 'Amphissa' from either year or 2018 'Ascolano', which themselves were not different from 'Frantoio' or 'Leccino' from either year (Table 4.11). 'Leccino' had the greatest trunk diameter, with all other cultivars having smaller diameters.

*NWREC comparison of fall-planted trees vegetative growth, second year: 2018 planting year.* 'Frantoio' and 'Leccino' had greater shoot numbers than 'Ascolano' and 'Amphissa' (Table 4.12). All cultivars had greater trunk diameters that were nearly twice that of 'Ascolano'. Across two years of growth, and similar to the second year, 'Frantoio' and 'Leccino' had the greatest shoot numbers, followed by 'Ascolano' which was not different than 'Leccino', and 'Amphissa' which was not different from 'Ascolano' (Table 4.13). Also similar to the second year, 'Leccino', 'Amphissa', and 'Frantoio' had twice or nearly twice the trunk diameter of that of 'Ascolano'.

*NWREC comparison of fall-planted trees survival.* There were no differences based on cultivar in survival rates for trees planted at 1.5 years of age in 2018 and 2019, with trees of different planting years analyzed separately (as shown in Fig. 4.7).

*Woodhall comparison of fall-planted trees vegetative growth, first year: comparison of 2018, 2019 planting years.* Trees planted in 2019 had a greater shoot number and length than 2018 trees, which in terms of shoot length showed no growth and/or dieback over the growing season (Table 4.14). Impact of cultivar on trunk diameter varied based on planting year, with 2019 'Leccino' having the greatest diameter and followed by 2019 'Frantoio' and 'Amphissa', which were not different from all other cultivar-year combinations.

*Woodhall comparison of fall-planted trees vegetative growth, second year: 2018 planting year.* In the second year (Table 4.15) and across two years of growth

(Table 4.16), there were no significant differences between cultivars for shoot number, length, or trunk diameter.

*Woodhall comparison of fall-planted trees survival.* There were no differences based on cultivar in survival rates for trees planted at 1.5 years of age in 2018 and 2019, with trees of different planting years analyzed separately (as shown in Fig. 4.8).

Contrary to data seen for other sites and season, initially fall-planted 'Amphissa' and 'Ascolano' showed increased shoot lengths at NWREC, though in year two these same cultivars showed low shoot numbers, which may point to the inverse relationship between shoot number and length seen elsewhere in this study. Across two years of growth at NWREC, as seen in other sites and seasons, 'Frantoio' and 'Leccino' have increased shoot numbers, and these two cultivars plus 'Amphissa' have the greatest trunk diameters, again possibly pointing to differences in vigor between the cultivars. Notably, while cultivar differences are present in the first year at Woodhall, in the second year and across two years of cumulative growth, these differences are no longer significant. As mentioned above, fall-planted trees at Woodhall may have been under a greater level of water stress, with the temporary establishment irrigation not installed until summer 2020. This stress may have led to reduced growth in all cultivars, while at NWREC, irrigation was not a limiting factor, and cultivar differences in vigor were made more apparent.

**Conclusion**

This study demonstrates how, barring extreme winter cold events over the first three years, olive orchards may be successfully established with multiple cultivars in Oregon's climate. Results show how spring-planting may be preferable to fall-planting, and the importance of establishment irrigation. Without the ability to test the hypothesis of older, larger trees showing better establishment than smaller, younger trees, we are not able to say if up-potting and overwintering gives an advantage, as high amounts of vegetative growth were seen in trees transplanted at both sizes and ages. Across both sites, production systems, and multiple years, 'Leccino', 'Frantoio', and to a slight lesser extent 'Amphissa' show increased growth compared to 'Ascolano', suggesting that these cultivars seen widely as too vigorous for super-high or high-density plantings in other regions, may be more well-adapted to growing in a climate such as Oregon's. Future research will be required to determine if these cultivars produce acceptable yields, as well as to evaluate their growth during establishment periods with colder temperatures.

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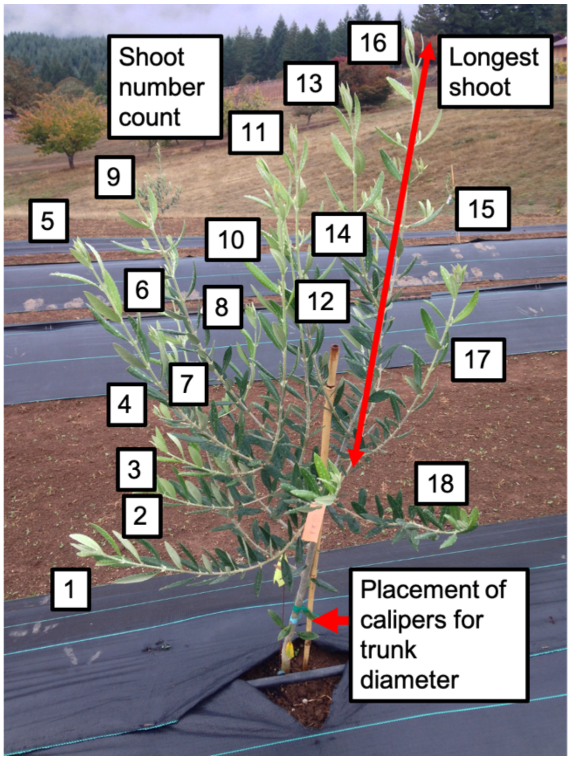


Fig. 4.1. Example of vegetative growth data collection. Shoot numbers begin at lower left and continue up and round the plant. Some actual shoots may not be visible in the photograph or included in the example count. Longest shoot was measured from the trunk to the shoot apex. Trunk diameter was measured at 10 cm from soil surface.

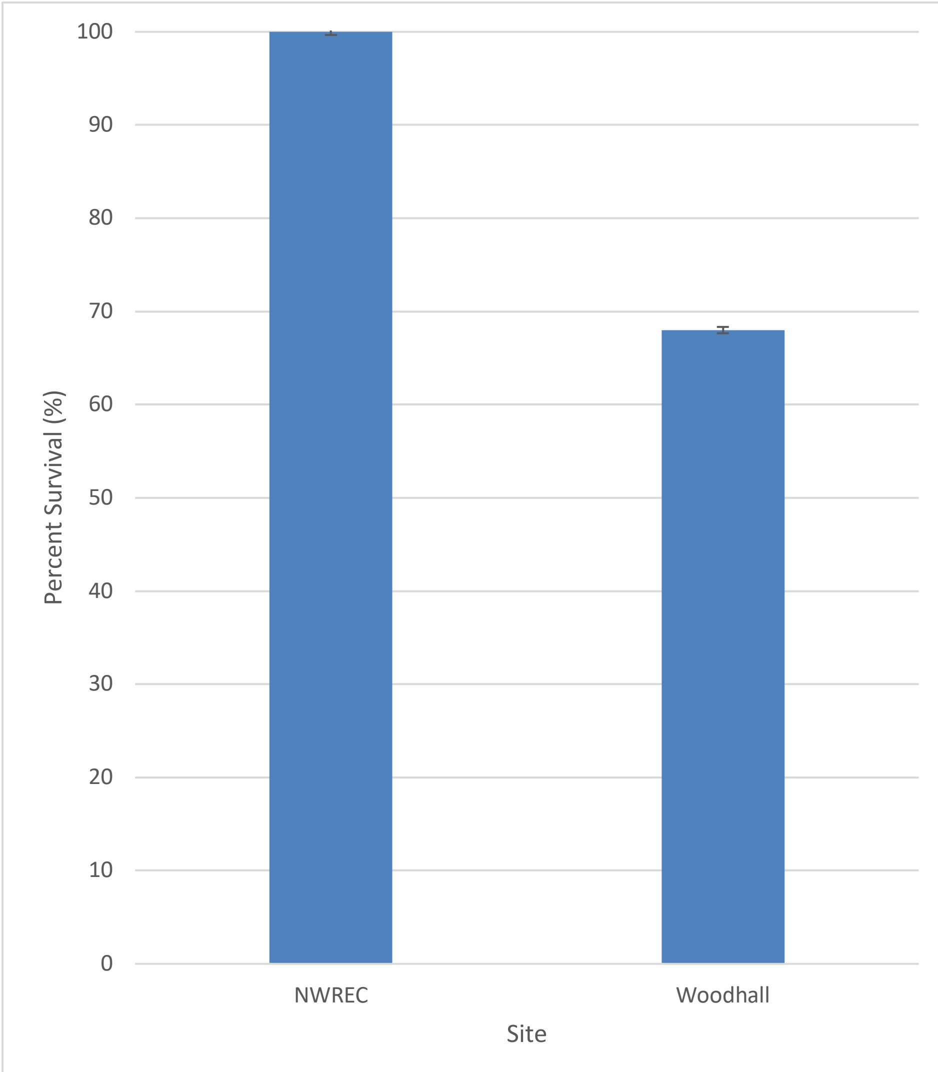


Fig. 4.2. Percent survival as of Fall 2020 for two-year-old olive trees planted Spring 2019, at NWREC (Aurora, OR) and Woodhall (Monroe, OR) ($P < .0001$).

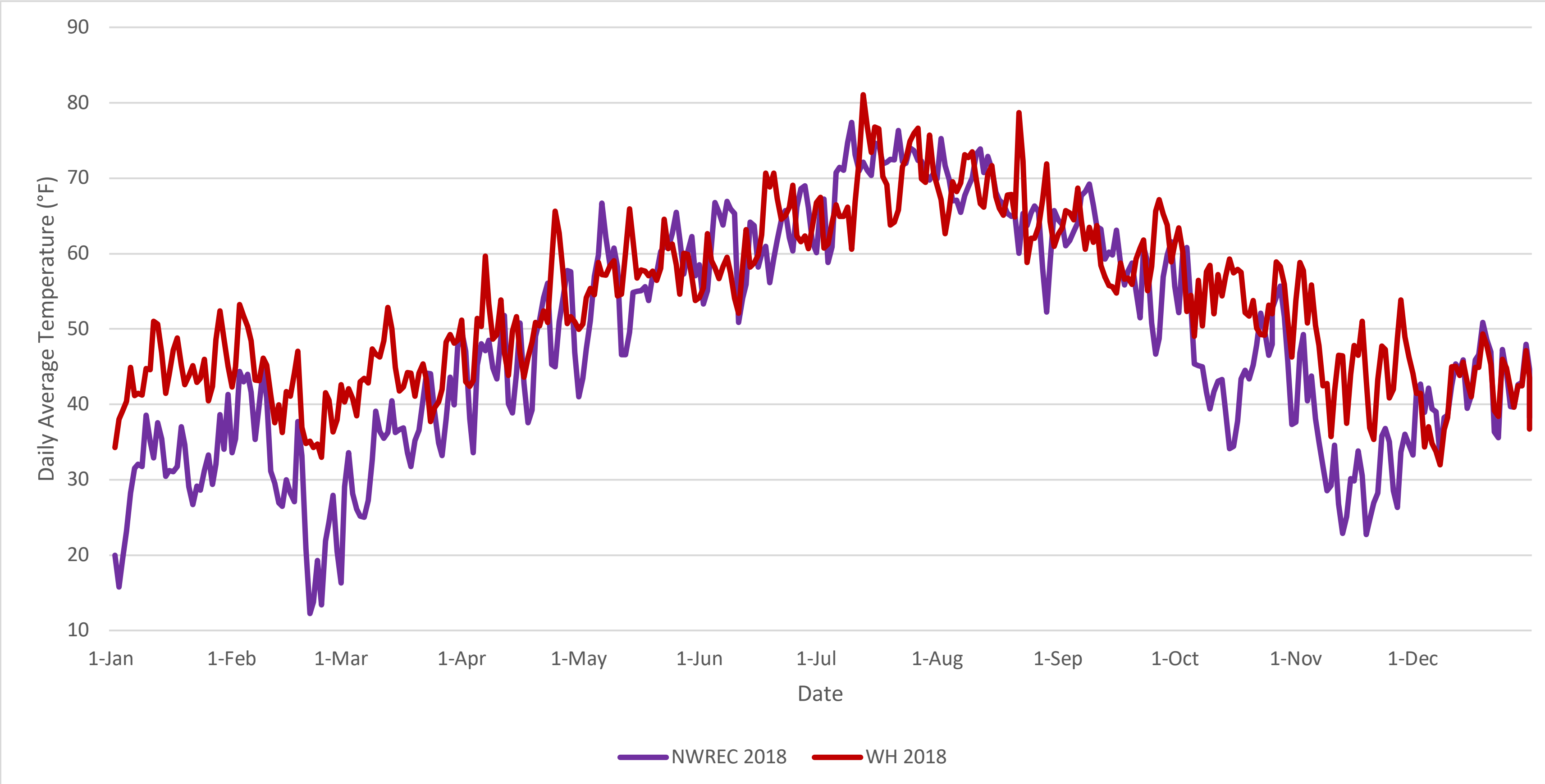


Fig. 4.3a. Daily average temperature Jan. through Dec. 2018. Aurora, OR and Corvallis, OR AgriMet (USBR, 2021) data was used to approximate site temperatures for NWREC (Aurora, OR) and Woodhall.

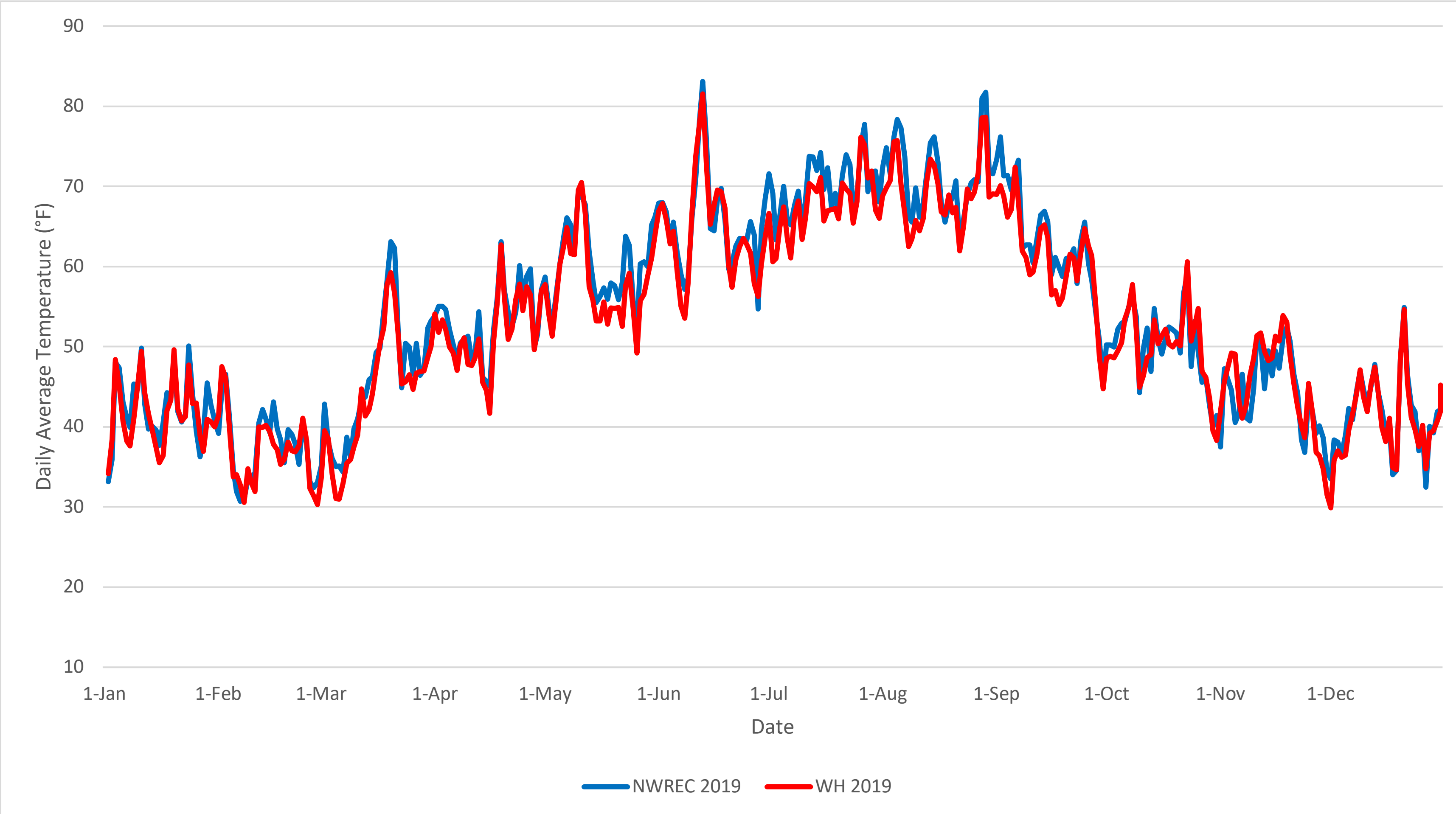


Fig. 4.3b. Daily average temperature Jan. through Dec. 2019. Aurora, OR (NWREC) and Monroe, OR (Woodhall).

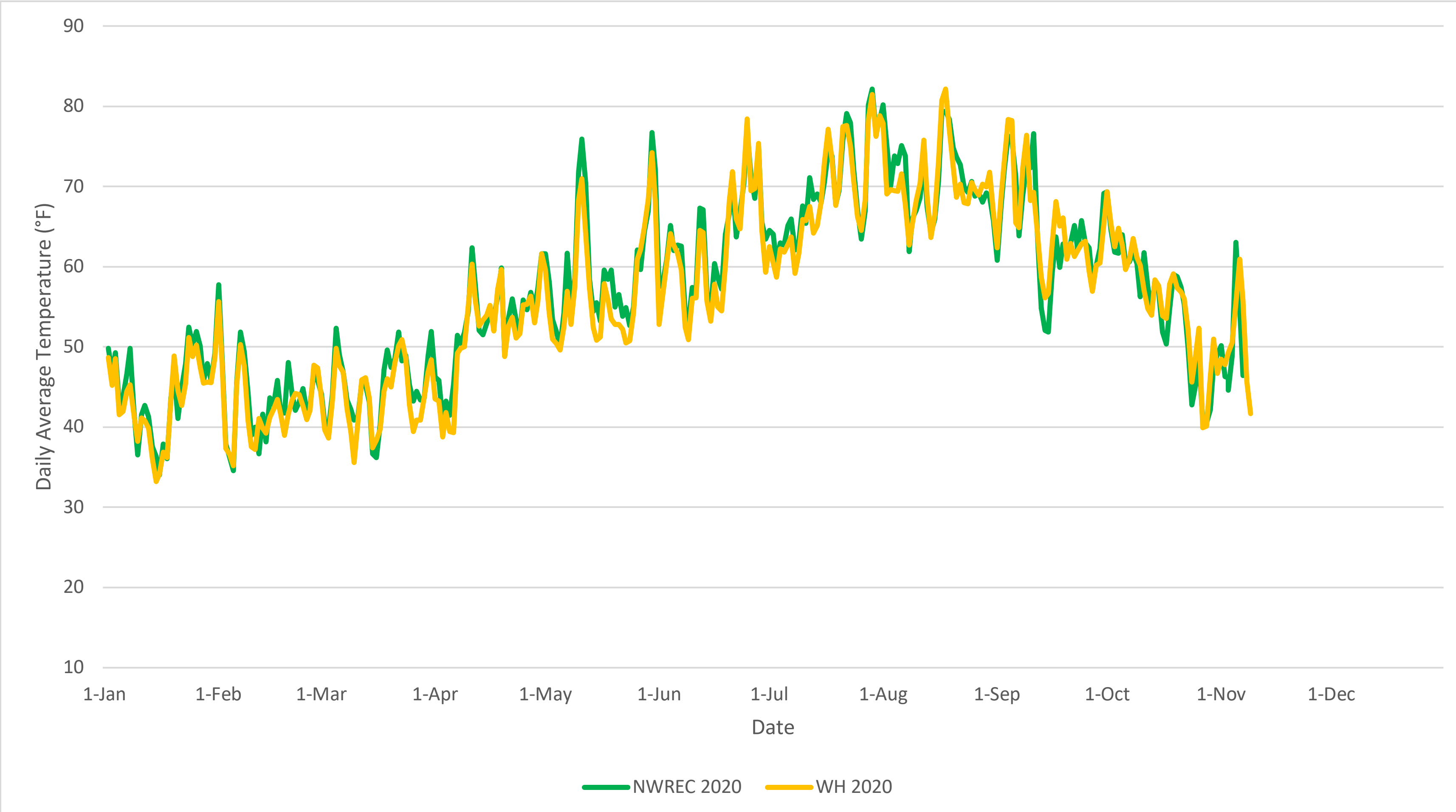


Fig. 4.3c. Daily average temperature Jan. through Dec. 2020. Aurora, OR (NWREC) and Monroe, OR (Woodhall).

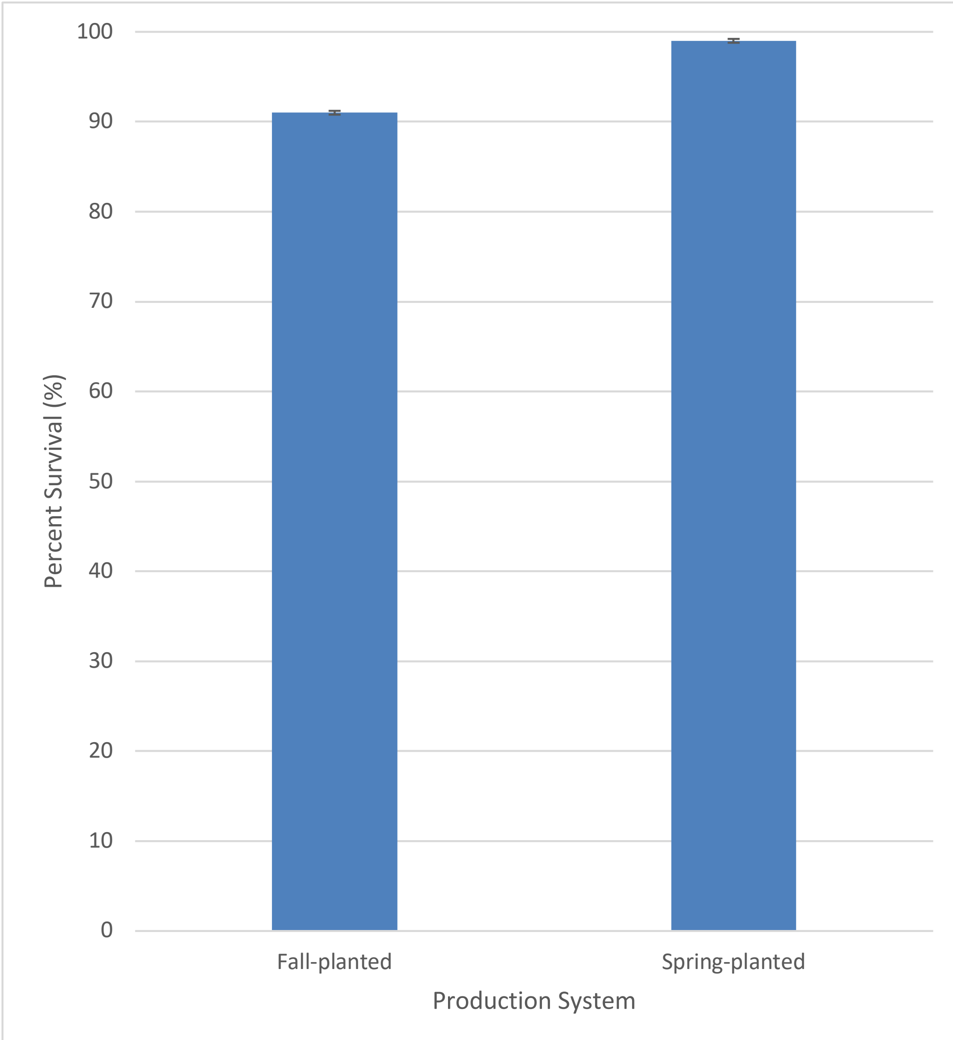


Fig. 4.4. Percent survival based on production system, for olive trees planted at NWREC (Aurora OR), after one or two growing seasons averaged across tree age (P = 0.0283 for production system, tree age was NS).

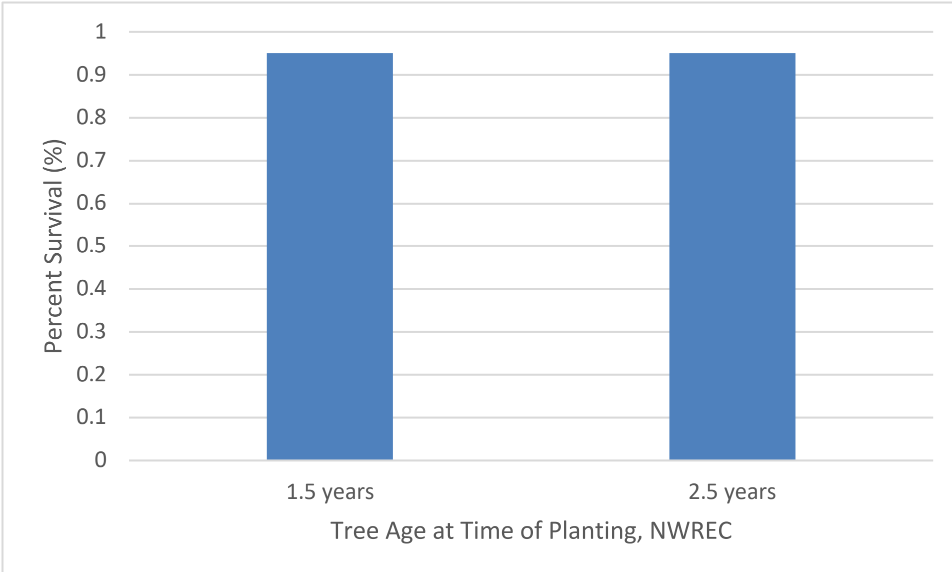


Fig. 4.5. Percent survival for 3.5-year-old olive trees fall-planted at 1.5 and 2.5 years of age, respectively, at NWREC (Aurora, OR) (NS; $P > .05$).

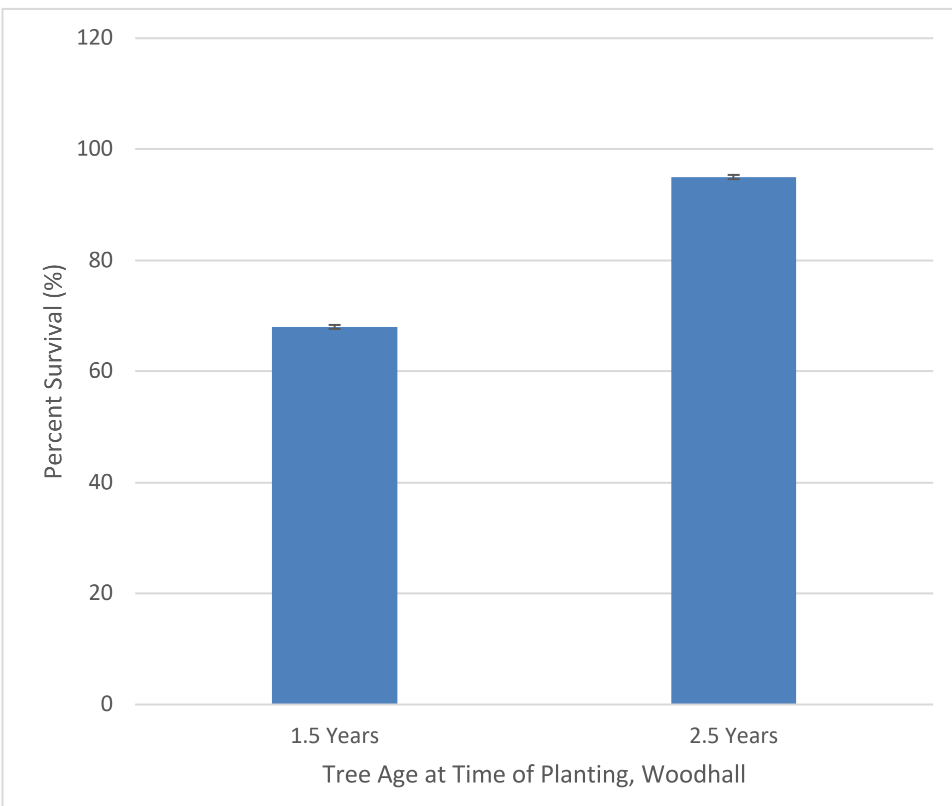


Fig. 4.6. Percent survival for 3.5-year-old olive trees fall-planted at 1.5 and 2.5 years of age, respectively, at Woodhall (Monroe, OR) ($P = 0.0019$).

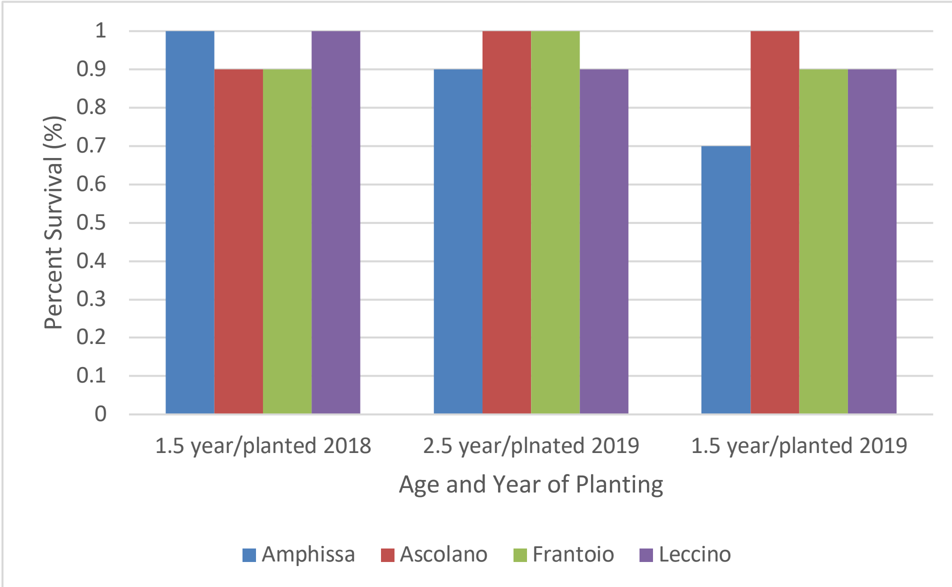


Fig. 4.7. Percent survival as of November 2020 for olive trees fall-planted at 1.5 and 2.5 years of age, respectively, in 2018 and 2019 at NWREC (Aurora, OR) (NS; P > .05).

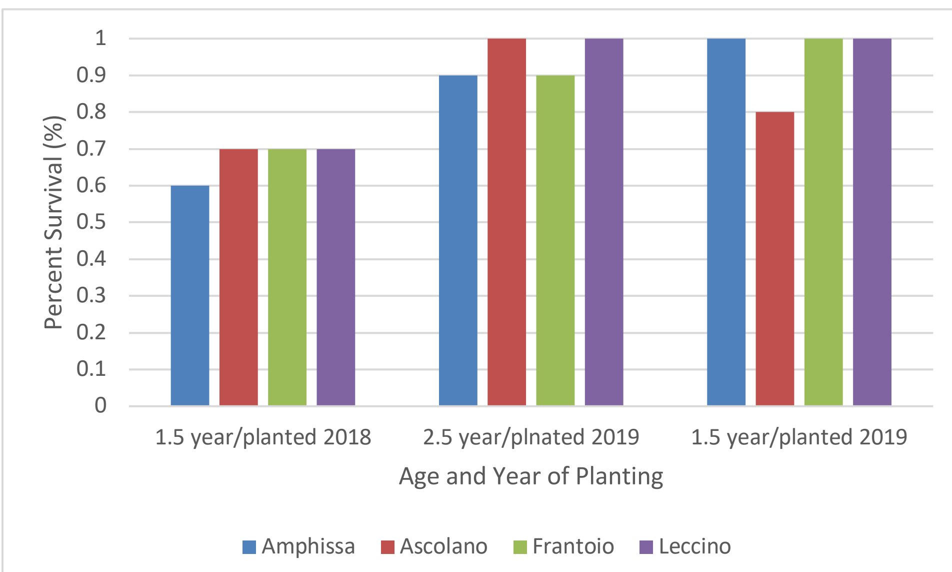


Fig. 4.8. Percent survival as of November 2020 for olive trees fall-planted at 1.5 and 2.5 years of age, respectively, in 2018 and 2019 at Woodhall (Monroe, OR) (NS; P > .05).

Table 4.1. Total nitrogen applied in olive fields, 2018-20.

| Year | Nitrogen ($kg \cdot ha^{-1}$) Applied per Site | | | |
|---|---|---|---|---|
| | NWREC Spring-planted | Woodhall Spring-planted | NWREC Fall-planted | Woodhall Fall-planted |
| *2018* | 1.94 | 1.76 | NA | NA |
| *2019* | 56.04[z] | 44.83 | 44.83 | 44.83 |
| *2020* | 56.04 | 56.04 | 56.04 | 56.04 |

[z]In 2019, NWREC spring-planted field received one more application than the other fields due to the observation that trees were putting on excessive late-season growth, and as such, fertilization program was halted immediately for the season.

Table 4.2. Effect of site, planting year, and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at time of planting (June/July) and at the end of the first growing season (November) for olive trees planted in 2018, 2019, and 2020 at the North Willamette Research and Extension Center (Aurora, OR) and Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 5).

| Treatments | Difference in Shoot No. | | | Difference in Length of Longest Shoot (cm) | | | Difference in Trunk Diameter (mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Site** | | | | | | | | | |
| NWREC | | 14 | | | 43 | | | 5 a[z] | |
| Woodhall | | 12 | | | 38 | | | 3 b | |
| **Planting Year** | | | | | | | | | |
| 2018 | | 10 b | | | 39 b | | | 3 b | |
| 2019 | | 23 a | | | 62 a | | | 5 a | |
| 2020 | | 7 b | | | 20 c | | | 3 b | |
| | | **Planting Year** | | | **Planting Year** | | | **Planting Year** | |
| **Cultivar** | 2018 | 2019 | 2020 | 2018 | 2019 | 2020 | 2018 | 2019 | 2020 |
| Amphissa | 13 bcd | 18 bc | 4 cd | 42 bcd | 61 ab | 8 e | 5 ab | 5 ab | 1 c |
| Ascolano | 4 d | 15 bcd | 5 cd | 21 de | 58 abc | 28 de | 2 bc | 3 bc | 3 bc |
| Frantoio | 6 bcd | 19 b | 10 bcd | 35 cd | 57 abc | 18 de | 3 bc | 5 abc | 4 abc |
| Leccino | 15 bcd | 38 a | 8 bcd | 57 abc | 72 a | 26 de | 3 bc | 7 a | 4 abc |
| **Significance**[y] | | | | | | | | | |
| *Site(S)* | | ns | | | ns | | | 0.0012 | |
| *Planting Year(Y)* | | <.0001 | | | <.0001 | | | 0.0008 | |
| *Cultivar(C)* | | <.0001 | | | 0.0006 | | | 0.0048 | |
| *S x Y* | | ns | | | ns | | | ns | |
| *S x C* | | ns | | | ns | | | ns | |
| *Y x C* | | 0.0035 | | | 0.0064 | | | 0.0040 | |
| *S x Y x C* | | ns | | | ns | | | ns | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.3. Effect of site, planting year, and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken one year since planting (June) and at the end of the second growing season (November) for olive trees planted in 2018 and 2019 at the North Willamette Research and Extension Center (Aurora, OR) and Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 5).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|
| **Site** | | | |
| NWREC | 58 a[z] | 35 | 9 |
| Woodhall | 41 b | 38 | 7 |
| **Planting Year** | | | |
| 2018 | 44 | 43 a | 6 b |
| 2019 | 55 | 30 b | 10 a |
| **Cultivar** | | | |
| Amphissa | 46 | 47 a | 9 ab |
| Ascolano | 46 | 27 b | 6 b |
| Frantoio | 53 | 41 ab | 7 ab |
| Leccino | 53 | 32 ab | 10 a |
| **Significance**[y] | | | |
| *Site(S)* | 0.0317 | ns | ns |
| *Planting Year(Y)* | ns | 0.0138 | <.0001 |
| *Cultivar(C)* | ns | 0.0241 | 0.0082 |
| *S x Y* | ns | ns | ns |
| *S x C* | ns | ns | ns |
| *Y x C* | ns | ns | ns |
| *S x Y x C* | ns | ns | 0.0333 |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.4. Effect of site, planting year, and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at planting (June/July) and at the end of the second growing season (November) for olive trees planted in 2018 and 2019 at the North Willamette Research and Extension Center (Aurora, OR) and Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 5).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|
| **Site** | | | |
| NWREC | 103 a[z] | 70 | 16 |
| Woodhall | 72 b | 72 | 14 |
| **Planting Year** | | | |
| 2018 | 67 b | 60 b | 11 b |
| 2019 | 108 a | 82 a | 19 a |
| **Cultivar** | | | |
| Amphissa | 71 b | 81 a | 17 ab |
| Ascolano | 67 b | 55 b | 11 c |
| Frantoio | 97 ab | 76 a | 13 bc |
| Leccino | 115 a | 73 ab | 19 a |
| **Significance**[y] | | | |
| *Site(S)* | 0.0104 | ns | ns |
| *Planting Year(Y)* | 0.0007 | 0.0002 | <.0001 |
| *Cultivar(C)* | 0.0119 | 0.0064 | 0.0002 |
| *S x Y* | ns | ns | ns |
| *S x C* | ns | ns | ns |
| *Y x C* | ns | ns | ns |
| *S x Y x C* | ns | 0.0499 | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.5. Effect of site and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at time of planting (July), and at the end of the third growing season (November) for olive trees planted in 2018 at the North Willamette Research and Extension Center (Aurora, OR) and Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 7).

| Treatments | Difference in Shoot No. | | Difference in Length of Longest Shoot (cm) | | Difference in Trunk Diameter (mm) |
|---|---|---|---|---|---|
| **Site** | | | | | |
| NWREC | 258 a[z] | | 70 | | 24 |
| Woodhall | 169 b | | 82 | | 27 |
| | **Site** | | **Site** | | |
| **Cultivar** | NWREC | Woodhall | NWREC | Woodhall | |
| Amphissa | 240 ab | 123 b | 92 ab | 65 ab | 28 ab |
| Ascolano | 209 ab | 100 b | 57 b | 65 ab | 19 b |
| Frantoio | 224 ab | 268 b | 63 ab | 96 ab | 26 ab |
| Leccino | 358 a | 185 b | 70 ab | 100 a | 30 a |
| **Significance**[y] | | | | | |
| *Site(S)* | 0.0017 | | ns | | ns |
| *Cultivar(C)* | 0.0105 | | ns | | 0.0288 |
| *S x C* | 0.0384 | | 0.0062 | | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.6. Effect of year, production system, and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at time of planting (spring or fall) and at the end of the first growing season (November) for olive trees planted in 2018-2019 and 2019-2020 at the North Willamette Research and Extension Center (Aurora, OR) (n = 7).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | | | | Difference in Trunk Diameter (mm) | |
|---|---|---|---|---|---|---|---|
| | | **Production System** | | | | | |
| **Year** | | Fall | Spring | | | | |
| 2018-19 | 41 a[z] | 14 c | 66 a | | | 7 a | |
| 2019-20 | 24 b | 15 c | 30 b | | | 5 b | |
| | | **Cultivar** | | | | | |
| **Production System** | | Amphissa | Ascolano | Frantoio | Leccino | | |
| Fall-planted | 46 a | 20 cde | 28 bcd | 5 de | 5 e | 7 a | |
| Spring-planted | 19 b | 40 abc | 47 ab | 52 ab | 53 a | 5 b | |
| | | **Planting Year** | | | | **Planting Year** | |
| **Cultivar** | | 2018-19 | 2019-20 | | | 2018-19 | 2019-20 |
| Amphissa | 25 b | 45 a | 15 c | | | 7 ab | 4 b |
| Ascolano | 29 ab | 37 abc | 38 abc | | | 4 b | 5 b |
| Frantoio | 37 ab | 41 ab | 15 c | | | 7 ab | 6 b |
| Leccino | 39 a | 36 abc | 22 bc | | | 10 a | 7 b |
| **Significance[y]** | | | | | | | |
| *Year(Y)* | <.0001 | <.0001 | | | | 0.0013 | |
| *Production System(P)* | <.0001 | <.0001 | | | | 0.0004 | |
| *Cultivar(C)* | 0.0146 | ns | | | | <.0001 | |
| *Y x P* | ns | <.0001 | | | | ns | |
| *Y x C* | ns | 0.0239 | | | | 0.0210 | |
| *P x C* | ns | 0.0042 | | | | ns | |
| *Y x P x C* | ns | ns | | | | ns | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[y] $P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.7. Effect of production system and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken one year since planting (spring or fall depending on treatment) and at the end of the second growing season (November) for olive trees planted in 2018-2019 at the North Willamette Research and Extension Center (Aurora, OR) (n = 9).

| Treatments | Difference in Shoot No. | | Difference in Length of Longest Shoot (cm) | | Difference in Trunk Diameter (mm) |
|---|---|---|---|---|---|
| **Production System** | | | | | |
| Fall-planted | 124 a[z] | | 14 b | | 13 a |
| Spring-planted | 68 b | | 30 a | | 11 b |
| | **Production System** | | **Production System** | | |
| **Cultivar** | Fall | Spring | Fall | Spring | |
| Amphissa | 70 b | 50 b | 11 c | 40 ab | 12 a |
| Ascolano | 83 b | 71 b | 19 bc | 18 bc | 7 b |
| Frantoio | 191 a | 73 b | 13 c | 46 a | 15 a |
| Leccino | 155 a | 76 b | 11 c | 15 c | 14 a |
| **Significance**[y] | | | | | |
| *Production System(P)* | <.0001 | | 0.0002 | | 0.0052 |
| *Cultivar(C)* | <.0001 | | 0.0259 | | <.0001 |
| *P x C* | 0.0031 | | 0.0051 | | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.8. Effect of production system and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at planting (spring or fall depending on treatment) and at the end of the second growing season (November) for olive trees planted in 2018-2019 at the North Willamette Research and Extension Center (Aurora, OR) (n = 9).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | | Difference in Trunk Diameter (mm) |
|---|---|---|---|---|
| **Production System** | | | | |
| Fall-planted | 182 | 17 b[z] | | 21 |
| Spring-planted | 149 | 80 a | | 20 |
| | | **Production System** | | |
| **Cultivar** | | Fall | Spring | |
| Amphissa | 102 b | 21 c | 80 ab | 20 a |
| Ascolano | 141 b | 19 c | 62 b | 13 b |
| Frantoio | 216 a | 15 c | 101 a | 22 a |
| Leccino | 204 a | 13 c | 77 ab | 25 a |
| **Significance[y]** | | | | |
| *Production System(P)* | ns | <.0001 | | ns |
| *Cultivar(C)* | <.0001 | 0.0293 | | <.0001 |
| *P x C* | ns | 0.0055 | | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.9. Effect of age at time of planting and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, over the second and first year in the field (November 2019-November 2020) for olive trees planted Nov. 2018 at 1.5 years old and Nov. 2019 at 2.5 years old, respectively, at the North Willamette Research and Extension Center (Aurora, OR) (n = 9).

| Treatments | Difference in Shoot No. | | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|---|
| **Age at Planting** | | | | |
| 1.5 year | 125 a[z] | | 14 | 13 a |
| 2.5 year | 75 b | | 7 | 8 b |
| | **Age at Planting** | | | |
| **Cultivar** | 1.5 year | 2.5 year | | |
| Amphissa | 70 c | 62 c | 11 | 12 a |
| Ascolano | 83 c | 91 bc | 10 | 7 b |
| Frantoio | 191 a | 81 c | 11 | 12 a |
| Leccino | 155 ab | 67 c | 9 | 11 a |
| **Significance**[y] | | | | |
| *Age at Planting(A)* | <.0001 | | ns | <.0001 |
| *Cultivar(C)* | 0.0003 | | ns | 0.0011 |
| *A x C* | 0.0006 | | ns | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.10. Effect of age at time of planting and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, over the second and first year in the field (November 2019-November 2020) for olive trees planted Nov. 2018 at 1.5 years old and Nov. 2019 at 2.5 years old, respectively, at the Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 6).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|
| **Age at Planting** | | | |
| 1.5 year | 23 a[z] | 16 a | 3 |
| 2.5 year | 12 b | 2 b | 2 |
| **Cultivar** | | | |
| Amphissa | 14 b | 8 | 2 ab |
| Ascolano | 15 ab | 6 | 1 b |
| Frantoio | 29 a | 7 | 4 a |
| Leccino | 12 b | 16 | 3 ab |
| **Significance**[y] | | | |
| *Age at Planting(A)* | 0.0064 | 0.0017 | ns |
| *Cultivar(C)* | 0.0139 | ns | 0.0461 |
| *A x C* | ns | ns | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.11. Effect of planting year and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at planting (November) and at the end of the first growing season for olive trees planted in 2018 and 2019 at the North Willamette Research and Extension Center (Aurora, OR) (n = 7).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | | Difference in Trunk Diameter (mm) |
|---|---|---|---|---|
| **Planting Year** | | | | |
| 2018 | 52 | 14 | | 8 |
| 2019 | 39 | 15 | | 6 |
| | | **Planting Year** | | |
| **Cultivar** | | 2018 | 2019 | |
| Amphissa | 38 | 28 ab[z] | 13 ab | 6 b |
| Ascolano | 43 | 15 ab | 41 a | 5 b |
| Frantoio | 47 | 10 b | <1 b | 7 b |
| Leccino | 53 | 3 b | 7 b | 10 a |
| **Significance**[y] | | | | |
| *Planting Year(P)* | ns | ns | | ns |
| *Cultivar(C)* | ns | 0.0014 | | 0.0004 |
| *P x C* | ns | 0.0187 | | ns |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.12. Effect of cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at one year since planting (November) and at the end of the second growing season for olive trees planted in 2018 at the North Willamette Research and Extension Center (Aurora, OR) (n = 9).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|
| **Cultivar** | | | |
| Amphissa | 70 b[z] | 11 | 16 a |
| Ascolano | 83 b | 19 | 8 b |
| Frantoio | 191 a | 13 | 15 a |
| Leccino | 155 a | 11 | 15 a |
| **Significance**[y] | | | |
| *Cultivar(C)* | <.0001 | ns | 0.0039 |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.13. Effect of cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at time of planting (November) and at the end of the second growing season for olive trees planted in 2018 at the North Willamette Research and Extension Center (Aurora, OR) (n = 9).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|
| **Cultivar** | | | |
| Amphissa | 123 c[z] | 21 | 24 a |
| Ascolano | 136 bc | 19 | 12 b |
| Frantoio | 259 a | 15 | 22 a |
| Leccino | 210 ab | 13 | 26 a |
| **Significance**[y] | | | |
| *Cultivar(C)* | 0.0003 | ns | <.0001 |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]$P$ value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.14. Effect of planting year and cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at planting (November) and at the end of the first growing season for olive trees planted in 2018 and 2019 at the Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 6).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) | |
|---|---|---|---|---|
| **Planting Year** | | | | |
| 2018 | 3 b[z] | 0 b | 1 b | |
| 2019 | 11 a | 9 a | 2 a | |
| | | | **Planting Year** | |
| **Cultivar** | | | 2018 | 2019 |
| Amphissa | 6 | 4 | 1 b | 2 ab |
| Ascolano | 5 | 4 | 1 b | 1 b |
| Frantoio | 10 | 2 | 1 b | 2 ab |
| Leccino | 8 | 8 | 1 b | 5 a |
| **Significance[y]** | | | | |
| *Planting Year(P)* | 0.0121 | 0.0017 | 0.0070 | |
| *Cultivar(C)* | ns | ns | ns | |
| *P x C* | ns | ns | 0.0419 | |

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]*P* value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.15. Effect of cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at one year since planting (November) and at the end of the second growing season for olive trees planted in 2018 at the Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 6).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|
| **Cultivar** | | | |
| Amphissa | 19 | 13 | 1 |
| Ascolano | 19 | 12 | 1 |
| Frantoio | 34 | 7 | 5 |
| Leccino | 21 | 32 | 4 |
| **Significance**[z] | | | |
| *Cultivar(C)* | ns | ns | ns |

[z]*P* value provided unless non-significant (ns; $P \geq 0.05$).

Table 4.16. Effect of cultivar on mean difference in shoot number for all shoots longer than 5 cm, mean difference in length of longest shoot from trunk to shoot apex, and mean difference in trunk diameter at 10 cm above soil surface, between measurements taken at planting (November) and at the end of the second growing season for olive trees planted in 2018 at the Oregon State University Woodhall III Vineyard (Monroe, OR) (n = 6).

| Treatments | Difference in Shoot No. | Difference in Length of Longest Shoot (cm) | Difference in Trunk Diameter (mm) |
|---|---|---|---|
| **Cultivar** | | | |
| Amphissa | 21 | 1 | 2 |
| Ascolano | 21 | 6 | 2 |
| Frantoio | 35 | 1 | 6 |
| Leccino | 15 | 0 | 5 |
| **Significance**[z] | | | |
| *Cultivar(C)* | ns | ns | ns |

[z]*P* value provided unless non-significant (ns; $P \geq 0.05$).

## 5. Conclusion

The Oregon Olive Grower Survey established finer-grain baseline data on olive production in the state than is otherwise available from other sources. The survey also demonstrated the importance of olive research in the state, both for orchard establishment considerations, as well as planning for successful long term crop production and management. Since the completion of the survey, new growers have joined the industry, and research consisting of the previous chapters has added to available production information for the region.

The propagation study demonstrated that multiple cultivars, including the past favorite 'Arbequina' but also including more recently popular 'Picual' and 'Leccino' can be successfully produced on-farm from mist-propagation of vegetative cuttings, though non-misted fall propagation may be just as effective for 'Arbequina'. Findings such as the higher root numbers, lengths, and percentages with 1:1 peat:perlite, and higher rooting capacity of 'Picual' as compared to 'Leccino', can be contrasted with propagation best practices developed and practiced in other regions, pointing to the continued need for regionally-specific production information.

Similarly, the field study demonstrated that cultivars that may be seen as too vigorous for other production styles ('Leccino' and 'Frantoio'), as well as lesser-studied cultivars such as 'Amphissa', may be well-suited to production in Oregon's climate. While winter temperatures during the study period did not allow for testing the hypothesis of the impact of tree size and age on orchard establishment, results showed that even in warmer years, spring-planting is preferable to fall-planting, as in California production systems.

Following these studies, and the stated preferences of Oregon olive growers, future studies will hopefully address fruit set in mature orchards, as well as address pest management issues that may arise as olive production area expands.

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# APPENDICES

Appendix A. OSU Oregon Olive Grower Survey Questions.

Q1 Do you consent to participate in this study?

Q2 Name:

Q3 Mailing Address:

Q4 Farm Name:

Q5 Farm Address:

Q6 What is your role on the farm? (Mark all that apply)

Farm Owner

Farm Manager

Other: ________________________________________________

Q7 Please complete the following table for your farm acreage.

| | |
|---|---|
| Acreage | |
| Total property acreage | |
| Total farmed acreage for any and all crops | |
| Total olive acreage (in production and/or planted) | |

Q8 Is your olive orchard/planting on a hill side (sloped terrain) or on valley floor (flat ground) property?

Hill side/sloped terrain

Valley floor/flat ground

Combination

Q9 Please list the olive cultivar(s) that you are currently growing with each cultivar separated by a comma.

Q10 Please complete the following table for the olive cultivar(s) that you currently grow. List only your five most important cultivars for which you have the most acreage in production.

| | Cultivar Name (example: Frantoio): | Source - Nursery or Grower Name (example: Santa Cruz Nursery): | Location of Source (example: Santa Cruz, CA): | Acres or Number of Plants in Production (example: 1 acre or 15 plants): | Plant Age at Purchase (example: 1 year old plants): | Container Size when Purchased (example: 4 inch cell): | Price per Plant (example: $5.50 each): |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |

Q11 Do you have available greenhouse/hoop house space for over-wintering your olive trees or for propagation?

Yes. Please describe with number, size, and type of structure (example: one 10’ x 100’ hoop house and one 20’ x 20’ propagation heated green house):

No

Q12 Do you propagate your own olives?

Yes/No

Q13 Describe your propagation process below.

Method of propagation (e.g. taking cuttings, grafting, etc):

Timing of propagation (e.g. fall, winter, spring, summer):

Do you use a misting system?

Do you use rooting hormones?

Q14 Did you plant your trees directly in the field as purchased or did you grow them to a larger size (up-pot) before planting in the field?

Yes (directly in field as purchased)

No (up-potted). Explain your up-potting process:

Q15 At what age did you plant your cultivars in the field after purchase (how old were they when planted)?

Q16 What time of the year (in general) did you plant your trees in the field?

Spring - Month:

Summer - Month:

Fall - Month:

Winter - Month:

Q17 Were your olives watered at planting? Are those plants irrigated or non-irrigated? Choose all that apply to your cropping system.

Yes, watered during year of establishment only

Yes, irrigated throughout the life of the planting

No, not irrigated

Q18 Did you lose any trees due to winter cold injury or freezing damage?

Yes/No

Q19 What percentage of your field planted trees were lost to freeze damage (approximately) when planted?

0-25%

25-50%

50-75%

75-100%

Q20 Do you fertilize your olive orchard?

Yes/No

Q21 What type of fertilizer do you apply? List your main three fertilizer sources.

| | Type (eg. urea, feather meal, custom blend synthetic, etc.): | Analysis (eg. 46-0-0, 12-0-0, 15-15-20, etc.): | Time of Application (eg. March to June, April, August to October, etc.): |
|---|---|---|---|
| Fertilizer 1 | | | |
| Fertilizer 2 | | | |
| Fertilizer 3 | | | |

Q22 What is the distance (in feet) between the trees in your orchard?

Feet between rows:

Feet between trees within rows:

Q23 Do you grow your olives for oil or table/brined olives?

Oil

Table/brined olives

Both

Q24 What has your total fruit production been for the last three years and on what acreage?

| | Total Production in Pounds (example: 800 lbs, 50 lbs): | On what acreage in production? (example: 1 acre, 0.8 or 3/4 acre, 20 trees): |
|---|---|---|
| 2015 | | |
| 2016 | | |
| 2017 | | |

Q25 What have your oil or table olive production been for the last three years?

| | Pounds or Gallons of Oil (example: 10 gallons of bulk oil, 200 lbs of oil): | Pounds of Table Olives - please specify type (example: 100 lbs of brined olives, 500 lbs of table olives): |
|---|---|---|
| 2015 | | |
| 2016 | | |
| 2017 | | |

Q26 How is your fruit processed? Check all that apply.

I process it on my own. Please indicate if they are table/brined olives, olive oil, or both:

I sell the fruit to a processor.

I contract processing for oil extraction and bottling and sell the finished product under my own brand.

Other:

Q27 Where do you process the oil? Please list the location and business name if applicable.

Q28 How do you sell your product? Please mark all that apply.

We sell the fresh fruit.

Our farm manages the sales of finished products.

Through a wholesale-distributor.

Other:

Q29 Where do you sell your product? Please mark all that apply.

To a processor as fruit

Direct farm sales

Farmers markets

Other local stores, restaurants and markets

Large-scale chain stores

Wholesale oil

Other:

Q30 Are you interested in producing table olives?

Yes

No

I already produce table olives.

Q31 Are you currently certified organic?

Yes/No

Q32 Are you interested in being certified organic?

Yes/No

Q33 On the following scale, rate your knowledge and understanding of the following for growing olives in Oregon. For this question, 1 = not knowledgeable, 2 = moderately knowledgeable, 3 = very knowledgeable.

| | Best practices for olive propagation in Oregon | Up-potting/ transplanting and over-wintering practices for olives | Olive cultivars best adapted to Oregon |
|---|---|---|---|
| 1 | ○ | ○ | ○ |
| 2 | ○ | ○ | ○ |
| 3 | ○ | ○ | ○ |

Q34 What are the greatest challenges/issues to your olive production (all topics count, anything affecting your production)?

Issue 1:

Issue 2:

Issue 3:

Q35 Do you know about OSU's current olive research?

Yes, I have heard about it.

No, I have not heard about it.

Q36 Would you like to learn more about OSU's current olive research and opportunities to collaborate? If you wish to be contacted with more information, select yes.

Yes, I would like to receive more information about the research project.

Yes, I would like to receive more information about the project and collaborative farm research.

No.

Q37 If you could ask OSU to research any topic pertaining to olive production in Oregon, what would your top three research priorities be?

Priority 1:

Priority 2:

Priority 3:

Appendix B. Branch and Twig Borer Identification.

Oregon State University

**Extension Service, Botany and Plant Pathology**
Oregon State University
1089 Cordley Hall, 2701 SW Campus Way
Corvallis, Oregon 97331

**P** 541-737-3472 | **F** 541-737-2412
http://plant-clinic.bpp.oregonstate.edu/

## Plant Clinic Diagnostic Service

| | |
|---|---|
| **Date:** | **July 10, 2020** |
| **Plant clinic number:** | **E20-1044** |
| **Client:** | Javier Fernandez-Salvador<br>NWREC<br>15210 NE Miley Rd.<br>Aurora, OR 97002 |
| **Submitter:** | same as above |
| **Found**: | in olive twigs, branches, trunks<br>06/11/20 |

### *IDENTIFICATION:*

| | |
|---|---|
| **Common name**: | branch and twig borer |
| **Scientific name**: | Order: Coleoptera<br>Family: Bostrichidae<br>*Melalgus confertus* |

**Notes:**

Thank you for sending your sample to the OSU Plant Clinic.

Your sample contained several olive stems with borer damage and two adult branch and twig borer beetles.

Below is some information from a University of California IPM webpage about these beetles and their management in olives…

### Description of the Pest

The branch and twig borer adult is a 0.3 to 0.6 inch (7–15 mm) long beetle, mostly black with brown wing covers. The C-shaped, white larvae are covered with fine hair. There is one generation per year.

Appendix C. Black Scale Identification.

**Extension Service- Botany and Plant Pathology**
**Oregon State University,** 1089 Cordley Hall, 2701 SW Campus Way, Corvallis, Oregon 97331-2903
**T** 541-737-3472 | **F** 541-737-2412 | http://www.science.oregonstate.edu/bpp/Plant_Clinic/index.htm

## Plant Clinic Diagnostic Service

| | |
|---|---|
| **Date:** | **September 4, 2018** |
| **Plant clinic number:** | **E18-1433** |
| **Client:** | Tessa Barker<br>[redacted] |
| **Submitter:** | Javier Fernandez-Salvador<br>NWREC |
| **Found**: | from olive orchard<br>8/23/18<br>also reported spotting on leaves |

***IDENTIFICATION:***

| subsample ID | common name | scientific name |
|---|---|---|
| **Am1** | black scale | Order: Hemiptera<br>Family: Coccidae<br>*Saissetia oleae* |
| **Am7** | privet leafhopper | Order: Hemiptera<br>Family: Cicadellidae<br>*Fieberiella florii* |
| **Le3** | small, dark ladybug | Order: Coleoptera<br>Family: Coccinellidae<br>*Rhizobius* sp. |
| **Le4** | no insects | |
| **Fr1** | no insects | |

**Notes:**

Thank you for submitting your sample to the OSU Plant Clinic.

Appendix D. Tortricid Family Identification.

OSU
Oregon State
UNIVERSITY

**Extension Service- Botany and Plant Pathology**
**Oregon State University,** 1089 Cordley Hall, 2701 SW Campus Way, Corvallis, Oregon 97331-2903
**T** 541-737-3472 | **F** 541-737-2412 | http://www.science.oregonstate.edu/bpp/Plant_Clinic/index.htm

## Plant Clinic Diagnostic Service

| | |
|---|---|
| **Date:** | **December 14, 2018** |
| **Plant clinic number:** | **E18-2098** |
| **Client:** | Neil Bell & Javier Fernandez-Salvador<br>1320 Capital St. NE #110<br>Salem, OR 97301 |
| **Submitter:** | Erica Chernoh<br>PO Box 14007<br>Salem, OR 97309 |
| **Found**: | in terminal leaves of potted olive plants |

### *IDENTIFICATION:*

| | |
|---|---|
| **Common name**: | tortricidae caterpillars |
| **Scientific name**: | Order: Lepidoptera<br>Family: Tortricidae |

**Notes:**

Thank you for sending your sample to the OSU Plant Clinic.

The sample contained an olive stem with a tortricid caterpillar and a cast pupal case. The caterpillar had webbed itself a retreat out of the terminal leaves on the stem and was feeding there. The cast pupal case was found among some webbed leaves on a side branch of the stem.

The Torticidae are a diverse group with almost 1400 species known to occur in North America alone. The caterpillars of many tortricid species are leaf-roller or leaf-tiers (like yours was), but others can be stem, fruit or seed borers.

Some interesting features of the caterpillar you had were that it had 3, 3, 3, 2, and 2 subventral setae on the 1$^{st}$, 2$^{nd}$, 7$^{th}$, 8$^{th}$ and 9$^{th}$ abdominal segments respectively. It also had a six-spined anal fork. Below are some photos of the caterpillar and the cast pupal case for your records.