Soil solarization effects on plant growth variables of field-grown tree saplings

by
Simon Fraher

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in BioResource Research
(Honors Associate)

Presented December 21, 2016
Commencement June 2017

AN ABSTRACT OF THE THESIS OF

Simon Fraher for the degree of Honors Baccalaureate of Science in BioResource Research presented on December 21, 2016. Title: Soil solarization effects on plant growth variables of field-grown tree saplings.

Solarization could be an alternative to chemical controls for soil pathogens and weeds, and it may also influence plant growth factors. Biomass, shoot length, and AMF colonization were examined in red oak (*Quercus rubra)*, Mazzard cherry (*Prunus avium)*, and hawthorn (*Crataegus monogyna*) at J. Frank Schmidt & Son Co. nursery in Boring, Oregon. Solarization plastic was installed summer 2014. A nonsolarized treatment was included. Plants were then seeded. Plants were collected on two dates. Biomass, shoot length, and AMF colonization were measured, and differences were determined using a t-test. Red oak showed little difference between treatments. Mazzard cherry had greater shoot length in the early season solarized treatment. Hawthorn shoot length was greater in the nonsolarized treatment for both dates. Hawthorn root biomass was greater in the solarized treatment, while shoot biomass was greater in the nonsolarized treatment. Mazzard cherry and hawthorn had greater AMF colonization in the nonsolarized treatment. Red oak was examined for ectomycorrhizal fungi; few instances were observed. Solarization can reduce AMF colonization slightly, suggesting an impact on plant growth. Hawthorn may have grown less under the solarized treatment due to AMF suppression by solarization. Reduced pathogen inoculum may explain why solarized Mazzard cherry outgrew nonsolarized.

Abstract approved:_____

Jennifer Parke

Key Words: Soil solarization, arbuscular mycorrhizal fungi, Willamette Valley, ornamental nursery

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

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Simon Fraher, Author

Introduction

Soil solarization is a hydrothermal method of managing soil ecology, which works by inducing chemical, biological, and physical changes in the soil using solar radiation (FAO, 2003). Soil solarization was developed in Israel and first described by Katan et al. in 1976, and soon was adopted in the United States. It is now studied and utilized in over sixty countries (Schreiner et al., 2001). Many studies have been conducted in areas with high solar radiation, but little research has been done on the efficacy of solarization in the Pacific Northwest. There is also a dearth of information on the effects of solarization on plants and associated fungi grown in solarized soils in this area.

Traditional mulches are used to limit evaporation, provide a physical barrier against weeds, improve soil tilth, and reduce erosion (FAO, 2003). Solarization plastic is a special type of mulch used for pest control, consisting of a transparent and impermeable membrane that increases soil thermal properties even more than standard opaque mulches. The primary application for solarization is for direct thermal lethality on weeds and plant pathogens in soil (Katan and Gamliel, 2009). Pests such as insects and nematodes may also be controlled through solarization, although their mobility reduces the efficacy of this treatment option (Stapleton, 2008).

Soil solarization is an important alternative to chemical pest controls. Methyl bromide was a major control for soilborne pathogens until it was banned in the United States in 2005 by the Montreal Protocol on Substances that Deplete the Ozone Layer (Pinkerton et al., 2000). Solarization may be appropriate in settings that are limited by cost, government regulations, or health concerns. Organic agriculture is one such setting that often uses integrated pest management (IPM) control methods instead of chemical applications. In organic agriculture, there is often emphasis on enhancing plant-soil interactions using mycorrhizal fungi. Arbuscular mycorrhizal fungi (AMF) symbiotically exchange carbohydrates from plant roots while enhancing water and nutrient uptake for the plant. These fungi have positive effects on the plant, but they are harmed by methyl bromide and metam sodium, a fumigant often used in place of methyl bromide (Schreiner et al., 2001). AMF tend not to be very thermotolerant, and there is some evidence that solarization has negative effects on certain AMF in vegetable crops (Schreiner et al., 2001). Even if AMF populations are damaged, the removal of pests and pathogens may have a greater impact on plant growth.

To maximize efficacy of solarization, a thin transparent plastic sheet that lies close to the soil should be used. Polyethylene plastic that is transparent to shortwave radiation but reflective to longwave radiation is most effective at increasing the soil temperature. Per Wein's law, solar radiation has a shorter wavelength than terrestrial radiation (FAO, 2003). Solar radiation is converted to heat and stored in the soil, so having a barrier above the soil that is impermeable to longwave terrestrial radiation results in thermal energy being trapped. Sunlight can pass through, and subsequent emissions from the soil are bounced back into the soil due to the reflective nature of the plastic. This explains the reasoning for choosing clear plastic over black plastic: soil beneath the cover absorbs the solar emissions, not the plastic itself. Additionally, thermal conductivity and specific heat capacity of the soil are strongly linked to moisture content.

Water will increase both conductivity and specific heat capacity in soil, which increases the penetration of solar radiation and enhances the effects of solarization (Gamliel and Katan, 2012). Solarization is most effective with wet soil.

J. Frank Schmidt & Son Co. is an ornamental tree nursery in Boring, Oregon, which is seeking to adopt alternative pest management methods. Their major interest is in weed control, and they have conducted trial studies with promising results. It is not clear, however, how tree seedlings grown in solarized soil are impacted. Because solarization has such drastic effects on soil ecology, there may be impacts on beneficial microorganisms, such as mycorrhizae and nitrogen-fixers, as well as the pathogens and weeds. Solarization can potentially create an environment where microbes are greatly reduced or enhanced in the topsoil. This may also affect soil fertility. Most of the nursery's expenses are in labor (e.g. hand-pulling weeds); use of solarization could be beneficial for the industry by reducing labor costs.

Three of J. Frank Schmidt's primary crops are red oak (*Quercus rubra*), Mazzard cherry (*Prunus avium*), and hawthorn (*Crataegus monogyna*). The objectives of this study were to determine the effect of solarization on tree growth in these three species, as well as the impact solarization has on associated AMF. Variables chosen to measure the effects of solarization were plant biomass, shoot length, and the extent of mycorrhizal colonization on plants grown in solarized or nonsolarized soil.

Methodology

Field Methods

The field site (45°25'31.1"N 122°19'20.6"W) was prepared according to J. Frank Schmidt's standard field procedure: fallow ground was tilled and mounded into 4' wide beds with 3' aisles. Six 0.28-acre rows were used, for two different treatments of three tree species. Anticondensing solarization plastic was added to cover three rows at a time (Fig. 1), which were assigned in groups according to the solarization treatment; control (non-solarized) rows were left uncovered. The edges of the plastic were buried to maximize the effects of solarization by reducing heat loss. The treatments were left undisturbed from 7/22/14 to 9/11/14. Plastic was then removed from the solarized bed, five shallow furrows made, and fertilizer added. On the plastic removal date, nonsolarized beds were treated with glyphosate and disked to kill any pre-existing weeds. The three tree species (*Q. rubra, P. avium, C. monogyna*) were then seeded.

Fig. 1. *Solarization plastic being removed prior to planting. Note that three rows are covered at a time, including the narrow aisles between rows. Bare earth rows between solarized soil are the nonsolarized treatment.*

Tree seedlings were dug by hand on two different collection dates, 6/23/15 and 9/10/15, to observe growth differences through the season. A spade was used to carefully harvest the seedlings with roots intact, taking care to dig near the center of the row to avoid any edge effects. Fifty plants were harvested from each of the three species and each treatment on both collection dates. The seedlings were gently shaken to remove soil, and then put in large plastic bags, tied shut, and put in a walk-in refrigerator for no more than two days. Extra care was taken to ensure the roots stayed moist during this time.

Lab Methods

On the first collection date, 25 seedlings of each species from both treatments were used for growth measurements, and an additional 25 plants were set aside for analysis of mycorrhizal colonization. On the second collection date, 50 plants were used for growth measurements and none were analyzed for mycorrhizal colonization.

Over the two days following each harvest, plants were washed and cut. Plant shoot length was measured from the lowest axillary bud to the apical meristem, rounding to the nearest 0.5 cm. The root and shoot were then separated by cutting along the lowest axillary bud. Next, roots were washed gently but thoroughly under running water to remove any soil, and gently shaken to dry.

On the first collection date, half of the collected plants were dried, and on the second date all plants were dried. Samples were put in labeled brown paper bags and stapled shut, then moved to drying ovens. The drying ovens were run for 48 hours at a temperature of 50°C, taking extra care to ensure airflow between the paper bags. Dry plant material was allowed to sit in the lab to adjust to ambient air moisture content before weighing. Digital balances (Mettler Toledo AE240, Columbus, Ohio, USA) were used to weigh the root and shoot materials of each seedling, and dry biomass readings were recorded to the closest 0.001 g. Dry plant material was then discarded. The shoot length determination, drying, and weighing process was repeated twice: once with plants from the first collection date, and once with plants from the second.

The second half of the plants from the first collection date was used for determination of mycorrhizal colonization. The plants to be cleared and stained had their shoots discarded, and their fine roots wrapped in a moist paper towel and moved to the walk-in refrigerator for later use. Cherry and hawthorn are hosts of AMF fungi, so their roots were cleared and stained to visualize mycorrhizal colonization (Fig. 2). Red oaks are ectomycorrhizal, so their roots were not cleared and stained but viewed under a microscope by Joyce Eberhart, Senior Faculty Research Assistant, to determine the presence or absence of ectomycorrhizae.

Later, the roots in cold storage were cleared and stained for AMF analysis. This was not a time sensitive step if the roots were not allowed to dry out; drying out would cause the roots to collapse and the hyphae of the AMF would become difficult to detect. All fine roots from the cherry and hawthorn subsamples were cut in lengths of approximately 1cm. Four sets of 50 mL Falcon tubes were labeled with species, treatment, and a number from 1 to 25. As fine roots were cut, they were added to these Falcon tubes with approximately 15 mL of 10% KOH, following a slightly modified staining protocol with trypan blue (Phillips and Hayman, 1970). The modification was only a substitution: lactoglycerin was used instead of lactophenol, for safety reasons. Cherry roots were autoclaved twice in KOH and the liquid was poured off to remove pigment and make the stained hyphae more visible.

Once cleared and stained, the percent root length of mycorrhizal colonization was assessed using a variation of the line intercept method (Giovanetti and Mosse, 1980). A 1 cm grid was drawn on a petri dish lid to act as a guide for counting the roots, similar to a hemocytometer. Stained samples were poured into a petri dish that was then set upon the inverted lid. Under a microscope (Wild 187077, Heerbrugg, Switzerland) at magnifications of 6x and 12x with a 15x eyepiece, the grid was followed and any intercepting root was counted as either mycorrhizal or nonmycorrhizal. First, horizontal lines were counted along, from left to right. Next the dish was rotated 90 degrees and the vertical lines were assessed in the same fashion. The count consisted of one hundred intercepts, and the number of mycorrhizal and nonmycorrhizal roots were recorded. If fewer than one hundred intercepts were present, the sample was not used. For plates that had >100 intercepts, only 100 intercepts were counted.

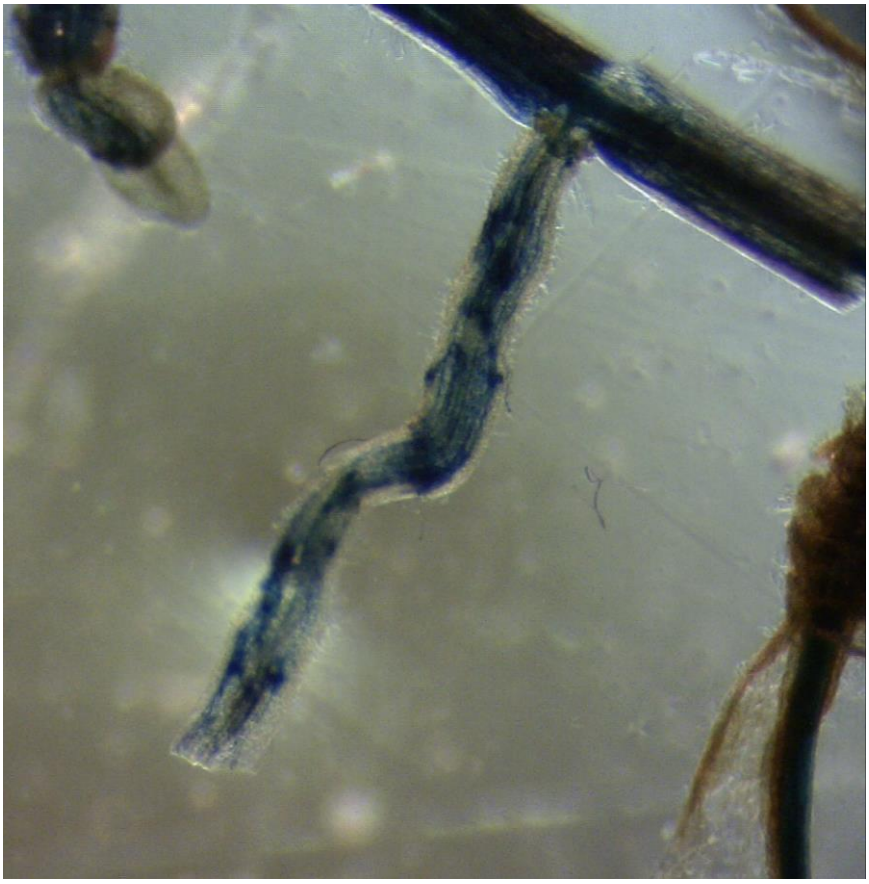

Fig. 2 *Magnified example of arbuscular mycorrhizal structures on a hawthorn root from the nonsolarized treatment from 6/23/15. A tiny network of hyphae within this root gives the AMF a diffuse appearance.*

Roots that were clear or very faintly tinted blue were considered nonmycorrhizal. Capillary action could cause the vascular tissue to absorb pigment making them difficult to interpret (Fig. 3) but these roots are still considered nonmycorrhizal. Mycorrhizal roots were either filled with a network of branching blue-stained hyphae, or had hyphae, which were clearly stained blue, emerging from the epidermis.

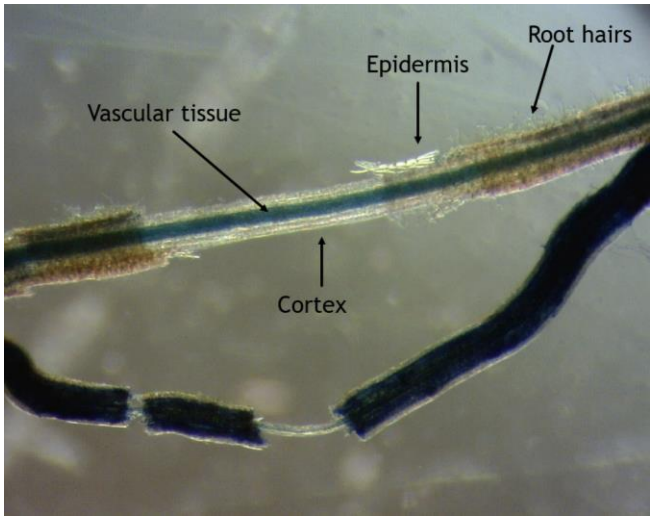

Fig. 3 *A nonmycorrhizal root (top) and a root with mycorrhizae present (bottom). Note that the vascular tissue within the cortex can uptake pigment through capillary action and appear dark, but this is not the same as the chitin of fungi becoming stained.*

Red oak root tips that were suspected to have ECM were next examined microscopically to confirm this presence or absence, and to determine extent of colonization. Roots were classified as mycorrhizal by the presence of a mantle and the absence of root hairs on the fine tips. Squash mounts were made of some tips that were not clearly ectomycorrhizal to confirm the presence or absence of a fungal mantle. Observations of percent mycorrhizal roots were not quantified.

Statistical Analysis

Statistical analyses were conducted using Microsoft Excel 2016. The ANOVA: single factor test was used, a part of the Analysis ToolPak add-in. The ANOVA model, or t-test, allows for comparison of solarization treatments within a species. A P-value of 0.05 or below was used to determine significance of results.

Results

T-tests were conducted to compare the effects of soil solarization on the following plant response factors: shoot length, shoot dry biomass, root dry biomass, and mycorrhizal colonization. These tests (Table 1) were conducted on the three tree species: mazzard cherry, red oak, and hawthorn. A significant result rejects the null hypothesis (H_0), and confirms the alternative hypothesis (H_1):

H_0: $\mu_{solarized} - \mu_{nonsolarized} = 0$
H_1: $\mu_{solarized} - \mu_{nonsolarized} \neq 0$

Here, μ represents the average of the measured variable (i.e. shoot length or weight). Rejecting the null hypothesis ($P < 0.05$) confirms a significant difference in treatments.

Collection Date 1: 6/23/15

Mazzard Cherry

The effect of solarization on Mazzard cherry shoot length early in the season (Fig. 4) was significant ($P < 0.001$) (Table 1). The effect of solarization on Mazzard cherry shoot biomass ($P = 0.99$) and root biomass ($P = 1.00$) early in the season was not significant. While shoot length was significantly larger in the solarized treatment, the biomass overall was the same for both. The null hypothesis for shoot length was rejected; the null hypothesis for both measures of biomass was not.

Fig. 4 *Noticeably greater shoot development in the solarized treatment of Mazzard cherry just prior to the first collection date, 6/23/15.*

Red Oak

There were no significant differences between solarization treatments in red oak shoot length ($P = 0.34$), root biomass ($P = 0.33$) or shoot biomass ($P = 0.65$) early in the season (Table 1). The null hypothesis for each of these factors could not be rejected.

Hawthorn

The hawthorn seedlings grown in nonsolarized plots had significantly greater shoot length ($P < 0.001$) and shoot biomass ($P < 0.001$) early in the season. Root biomass was greater in the solarized treatment ($P = 0.02$) (Table 1). In all three measured

variables, the null hypothesis was rejected. Hawthorns in the nonsolarized treatment performed better in all measurements except root biomass.

Mycorrhizae Results

Arbuscular Mycorrhizal Fungi (Mazzard Cherry, Hawthorn)

Mycorrhizal associations were documented on the first collection date, 6/23/15. Mazzard cherry and hawthorn roots were analyzed and using a t-test to determine significant differences between treatments (Table 3). The null and alternate hypotheses were identical to those used for the other variables

H_0: $\mu_{solarized} - \mu_{nonsolarized} = 0$
H_1: $\mu_{solarized} - \mu_{nonsolarized} \neq 0$

Mazzard cherry grown in nonsolarized soil had a greater average incidence of mycorrhizal colonization than did plants in the solarized soil treatment ($P < 0.001$). Hawthorn also had greater mycorrhizal colonization in the nonsolarized treatment, by almost 68% ($P < 0.001$). Solarization resulted in a reduction in AMF colonization for both species.

Ectomycorrhizal Fungi (Red Oak)

Red oak was examined for ectomycorrhizae, but so few examples were found that no conclusions could be made about statistically significant treatment differences. Of the 25 trees from each treatment, eight from nonsolarized plots and seven from solarized plots were examined for ECM. After microscopic analysis, it was determined that the solarized treatment had a numerically higher percent of ectomycorrhizal tips, as well as more types of ECM. Five of the eight trees from nonsolarized plots were nonmycorrhizal, one had only a single ectomycorrhizal tip observed, and the remaining two had less than half mycorrhizal roots. The mycorrhizal roots that were observed had thin smooth mantles, or light amounts of white emanating hyphae. All seven trees from solarized plots had at least some ECM. The trees from solarized plots had two types of ECM with reddish brown hyphae, as well as some of the thinner white types observed in the nonsolarized plots.

Collection Date 2: 9/10/15

Mazzard Cherry

The effect of solarization on Mazzard cherry shoot length ($P = 0.21$) and shoot biomass ($P = 0.97$) later in the season was not significant (Table 1). Roots for this sample were deemed too damaged by harvesting equipment and data on root biomass and AMF colonization were not collected. For the measured variables, there was no observed difference between treatments.

Red Oak

The effect of solarization on red oak was not significant for shoot length ($P = 0.11$), shoot biomass ($P = 0.73$), and root biomass ($P = 0.87$) later in the season (Table 1).

Hawthorn

The nonsolarized treatment showed greater hawthorn shoot length ($P < 0.001$) and shoot biomass ($P < 0.001$) later in the season (Table 1). The solarized treatment provided greater root biomass ($P = 0.01$). The null hypothesis was rejected for all three variables.

Discussion

Soil solarization is a complex treatment that is difficult to measure in terms of success or failure. Because soil solarization works by inducing chemical, biological, and physical changes in the soil, there are a lot of variables that may explain different outcomes. Also, growers may measure success in a number of different ways. This study has provided useful initial insight into three tree species, yet there is clearly more at work than the variables observed. Subsequent studies should look into the solarization effects on weed ecology, and how pathogens may be controlled to enhance crop vitality. At the microscopic level, soil microbes and soil fertility may also be drastically altered by solarization. Many factors were not accounted for in this study, as it was meant as a preliminary look into a much larger issue.

Two collection dates were used because the staff at J. Frank Schmidt nursery were curious about the effects of solarization early in the season, and what that led to later in the season. Plants grown from seed, such as the three tree species used here, have a major competitive edge if their growth is enhanced early in the season. Unfortunately, the data set was not robust enough to make conclusions about the differences in early and late growth for all three species.

The reason AMF associations were only documented on the first collection date is because colonization occurs early in the plant's life. Additionally, any advantage the plant has early on means it can better outcompete weeds, which have proven to be a major problem in the Oregon tree production industry.

Hawthorn had greater shoot length, shoot biomass, and AMF associations in the nonsolarized treatment on both sampling dates. The only measured variable in hawthorn that improved under the solarized regime was root biomass, and by a small margin. Considering the goals of growers, this is not necessarily a bad thing. Many of the ornamental trees grown by J. Frank Schmidt are used as rootstocks for grafting other trees, though hawthorn is not used for this purpose. For certain species, a more robust root stock may be the only thing they are interested in. Still, these results do not show solarization as a favorable treatment for hawthorn.

AMF colonization can have varying levels of importance in plant growth, depending on the species (Smith and Read, 2008). Both AMF and ECM fungi are able to colonize a wide range of host species, but the availability of inoculum may vary (Valyi, 2016). Ectomycorrhizal fungi spores may be wind dispersed, but they are often moved through another vector, like rodents. A mature oak (*Quercus garryanna)* with an established hyphal network can also inoculate seedlings with ECM, though first-year

seedlings must be within the root zone of the mature oak for this to occur. Seedlings far from a mature oak require rodent transmission of spores (Frank et al., 2009). The red oaks (*Quercus rubra)* grown at J. Frank Schmidt nursery were field-grown and well-isolated from any mature oaks, so the rodent vector may have been a primary source for inoculum. Arbuscular mycorrhizal fungi are also limited in their ability to spread over long distances, and they too can be transmitted through rodents. AMF can also spread propagules through collembolans and, especially, earthworms (Valyi, 2016). Earthworms likely vector AMF more effectively than ECM (Reddell and Spain, 1991). Thus, it is probable that a greater bank of AMF inoculum was in the soil bank than ECM inoculum. Earthworms are mobile in the soil, and can reenter solarized plots easily as soon as the temperatures return to a survivable level. This may explain why incidence of ECM presence was so low in red oak, but AMF associations were common in Mazzard cherry and hawthorn. It would be prudent to determine if the worm vector makes a major difference between treatments and species in a future field study, and also to assess the extent of rodent presence in the area.

Another explanation for hawthorn's greater growth in the nonsolarized setting is a greater dependence on AMF than Mazzard cherry. This could explain why hawthorn performed more poorly under the solarized treatment: soil fertility and water may have been more accessible to Mazzard cherry via AMF. Another possibility is that Mazzard cherry benefitted more from reduced pathogen inoculum in the soil than did hawthorn. On the Pacific Northwest Pest Management Handbook search engine for plant disease, hawthorn appears to suffer fewer diseases than cherry. The pathogens of *Crataegus* species (including rust, scab, and mildew) are transmitted through secondary hosts and through infected plant litter. Soil pathogens are not of much concern in this genus. *Prunus* species, however, are susceptible to various cankers, root rots, and nematodes, which are all potentially controlled through solarization. Reduction in disease inoculum and nematode populations could account for the greater growth in Mazzard cherry in the solarized treatment. Hawthorn, conversely, may have little to gain from the reduction in soil pathogens that solarization may cause, and may even be hindered by it when loss of beneficial microbes is also considered. Mycorrhizae are more resistant to solarization than most pathogenic fungi (Elmore et al., 1997). While no data were collected on pathogenic fungi, it was observed that AMF were more prevalent in nonsolarized soil treatments. Solarization did reduce mycorrhizal colonization in Mazzard cherry to a small extent. In hawthorn, solarization reduced mycorrhizal associations to a much greater extent. Hawthorn was the only species to demonstrate more nonmycorrhizal than mycorrhizal roots under any treatment, and that treatment was solarized soil.

It would be useful to design an experiment to test the dependency upon AMF in several tree species. This could be done in a laboratory setting using treatments with sterile soil and sterile soil inoculated with AMF. Plant growth differences could be measured in much the same way as this project (height, biomass) but having laboratory conditions would allow for experimental controls to determine the actual effect of AMF presence. It would also be useful to see an analysis of micro and macronutrients in the plant, as well as a comparison of wet vs dry biomass to assess if the AMF were significantly affecting nutrient and water uptake. The term AMF refers to a diverse group of fungi, many of which provide different advantages to different plant species (Hart et al., 2003). Having a diverse population of AMF can affect plant species richness, and can

even result in mycelial networks forming between plant species (Hart et al., 2003). It would be important to experiment with different individual AMF species, and different groups of species, as they interact with various plant species. Although J. Frank Schmidt grows their trees in monoculture rows, it may be that their plants could benefit even more greatly from intermixed plantings to promote AMF species diversity. There may also be major benefits to using rotation cropping, so as to expose crops to a wide array of AMF species from previous crops.

Root biomass, shoot biomass, and shoot length were not significantly different between treatments for red oak. A greater sample size and observations of other variables may help draw more meaningful conclusions. One factor that was apparent in the field, yet not quantified, was that many of the trees in the nonsolarized treatment had higher branching. The trees in the solarized treatment were mostly single-stems. Depending on the grower's usage of the plant, this might be a useful starting point for further discovery. In the ECM assessment of red oak, it appeared that the solarized treatment promoted ECM development better than the nonsolarized treatment. However, so few observations were made that it would require further documentation before any conclusions can be drawn. It is certainly an intriguing first look at ECM in this species, however.

Only one variable of Mazzard cherry was significantly different after solarization: shoot length from the first collection date. Here, shoots were an average of about 40% greater in solarized trials. All other results were not significant. Mazzard cherry is used as both a rootstock for grafting other cherry cultivars, and as a source of shoots. Depending on the end use, greater shoot growth may or may not be useful. However, when considering weeds, it is important to grow taller faster than any competitors. For this reason, solarization could potentially give an advantage to Mazzard cherry, though a more in-depth weed study would be necessary to support this conclusion.

Many publications have touted the use of solarization as a management tool, first for pathogen control, later for weed control. More recent work is questioning the effects of solarized soil on crops; this study addressed some of those questions. In August 2016, a follow-up study found that seedling stand density, stem caliper, and stem height of cherry, linden, and oak were all greater in solarized treatments, but hawthorn once again performed better in the nonsolarized treatment (Parke, personal communication). This information only begins to explain a complex issue with countless factors. Different species react differently to solarization (Smith and Read, 2008). Larger-scale studies with better documentation will lead to greater understanding of these complex chemical, biological, and physical changes in the soil and how they affect tree growth in the Willamette Valley.

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Tables and Figures

Mazzard Cherry 6/23/15					
Shoot Length					
Source of Variation	SS	df	MS	F	P-value
Between Groups	2067.25	1.00	2067.25	21.25	<0.001
Within Groups	4669.70	48.00	97.29		
Total	6736.95	49.00			
Shoot Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	0.00	1.00	0.00	0.00	0.99
Within Groups	236.61	98.00	2.41		
Total	236.61	99.00			
Root Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	0.00	1.00	0.00	0.00	1.00
Within Groups	43.85	98.00	0.45		
Total	43.85	99.00			

Red Oak 6/23/15					
Shoot Length					
Source of Variation	SS	df	MS	F	P-value
Between Groups	28.13	1.00	28.13	0.91	0.34
Within Groups	1484.00	48.00	30.92		
Total	1512.13	49.00			
Shoot Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	0.24	1.00	0.24	0.21	0.65
Within Groups	110.90	97.00	1.14		
Total	111.14	98.00			
Root Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	0.23	1.00	0.23	0.97	0.33
Within Groups	22.98	97.00	0.24		
Total	23.21	98.00			

Hawthorn 6/23/15					
Shoot Length					
Source of Variation	SS	df	MS	F	P-value
Between Groups	1415.12	1.00	1415.12	59.57	<0.001
Within Groups	1140.36	48.00	23.76		
Total	2555.48	49.00			
Shoot Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	13.30	1.00	13.30	37.83	<0.001
Within Groups	34.45	98.00	0.35		
Total	47.74	99.00			
Root Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	0.40	1.00	0.40	5.69	0.02
Within Groups	6.84	98.00	0.07		
Total	7.23	99.00			

Mazzard Cherry 9/10/15					
Shoot Length					
Source of Variation	SS	df	MS	F	P-value
Between Groups	1726.40	1.00	1726.40	1.57	0.21
Within Groups	107547.85	98.00	1097.43		
Total	109274.25	99.00			
Shoot Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	0.36	1.00	0.36	0.00	0.97
Within Groups	21681.00	97.00	223.52		
Total	21681.36	98.00			
Root Dry Mass					
Source of Variation	SS	df	MS	F	P-value
Between Groups	NA	NA	NA	NA	NA
Within Groups	NA	NA	NA		
Total	NA	NA			

Red Oak 9/10/15					
Shoot Length					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	930.25	1.00	930.25	2.55	0.11
Within Groups	35714.61	98.00	364.43		
Total	36644.86	99.00			
Shoot Dry Mass					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	13.16	1.00	13.16	0.12	0.73
Within Groups	10858.47	98.00	110.80		
Total	10871.63	99.00			
Root Dry Mass					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	1.57	1.00	1.57	0.03	0.87
Within Groups	5801.63	98.00	59.20		
Total	5803.21	99.00			

Hawthorn 9/10/15					
Shoot Length					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	10652.19	1.00	10652.19	25.81	<0.001
Within Groups	40041.10	97.00	412.79		
Total	50693.29	98.00			
Shoot Dry Mass					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	553.68	1.00	553.68	16.40	<0.001
Within Groups	3308.26	98.00	33.76		
Total	3861.94	99.00			
Root Dry Mass					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	37.51	1.00	37.51	6.44	0.01
Within Groups	570.57	98.00	5.82		
Total	608.08	99.00			

Table 1. *Results of the t-test for three documented variables (shoot length, shoot dry mass, root dry mass) for both collection dates.*

Mazzard Cherry 6/23/15

Shoot Length

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Length Solarized	25.00	1140.50	45.62	131.74
Shoot Length Nonsolarized	25.00	819.00	32.76	62.84

Shoot Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Dry Mass Solarized	50.00	158.59	3.17	3.28
Shoot Dry Mass Nonsolarized	50.00	158.46	3.17	1.55

Root Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Root Dry Mass Solarized	50.00	69.68	1.39	0.57
Root Dry Mass Nonsolarized	50.00	69.72	1.39	0.32

Oak 6/23/15

Shoot Length

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Length Solarized	25.00	522.50	20.90	26.50
Shoot Length Nonsolarized	25.00	560.00	22.40	35.33

Shoot Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Dry Mass Solarized	49.00	135.07	2.76	0.99
Shoot Dry Mass Nonsolarized	50.00	142.79	2.86	1.29

Root Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Root Dry Mass Solarized	49.00	60.66	1.24	0.20
Root Dry Mass Nonsolarized	50.00	66.72	1.33	0.27

Hawthorn 6/23/15

Shoot Length

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Length Solarized	25.00	391.50	15.66	34.20
Shoot Length Nonsolarized	25.00	657.50	26.30	13.31

Shoot Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Dry Mass Solarized	50.00	25.91	0.52	0.11
Shoot Dry Mass Nonsolarized	50.00	62.38	1.25	0.59

Root Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Root Dry Mass Solarized	50.00	25.91	0.52	0.11
Root Dry Mass Nonsolarized	50.00	19.62	0.39	0.02

Mazzard Cherry 9/10/15

Shoot Length

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Length Solarized	50.00	5129.50	102.59	1090.91
Shoot Length Nonsolarized	50.00	5545.00	110.90	1103.95

Shoot Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Dry Mass Solarized	50.00	1105.29	22.11	235.76
Shoot Dry Mass Nonsolarized	49.00	1089.11	22.23	211.02

Root Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Root Dry Mass Solarized	NA	NA	NA	NA
Root Dry Mass Nonsolarized	NA	NA	NA	NA

Oak 9/10/15

Shoot Length

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Length Solarized	50.00	1976.50	39.53	461.35
Shoot Length Nonsolarized	50.00	2281.50	45.63	267.52

Shoot Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Dry Mass Solarized	50.00	683.19	13.66	143.80
Shoot Dry Mass Nonsolarized	50.00	719.47	14.39	77.80

Root Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Root Dry Mass Solarized	50.00	851.26	17.03	63.02
Root Dry Mass Nonsolarized	50.00	863.79	17.28	55.38

Hawthorn 9/10/15

Shoot Length

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Length Solarized	49.00	2065.50	42.15	233.66
Shoot Length Nonsolarized	50.00	3145.00	62.90	588.28

Shoot Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Shoot Dry Mass Solarized	50.00	307.68	6.15	14.14
Shoot Dry Mass Nonsolarized	50.00	542.98	10.86	53.38

Root Dry Mass

Groups	*Count*	*Sum*	*Average*	*Variance*
Root Dry Mass Solarized	50.00	345.52	6.91	6.59
Root Dry Mass Nonsolarized	50.00	284.27	5.69	5.06

Table 2. *Basic statistics from the raw data set for three documented variables (shoot length, shoot dry mass, root dry mass) for both collection dates.*

Mazzard Cherry Solar

Groups	*Count*	*Sum*	*Average*	*Variance*
Mycorrhizal	24.00	1508.00	62.83	327.80
Non-mycorrhizal	24.00	892.00	37.17	327.80

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	7905.33	1.00	7905.33	24.12	<0.001
Within Groups	15078.67	46.00	327.80		
Total	22984.00	47.00			

Hawthorn Solar

Groups	*Count*	*Sum*	*Average*	*Variance*
Mycorrhizal	19.00	637.00	33.53	303.15
Non-mycorrhizal	19.00	1263.00	66.47	303.15

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	10312.53	1.00	10312.53	34.02	<0.001
Within Groups	10913.47	36.00	303.15		
Total	21226.00	37.00			

Mazzard Cherry Nonsolar

Groups	*Count*	*Sum*	*Average*	*Variance*
Mycorrhizal	24.00	1857.00	77.38	143.03
Non-mycorrhizal	24.00	543.00	22.63	143.03

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	35970.75	1.00	35970.75	251.50	<0.001
Within Groups	6579.25	46.00	143.03		
Total	42550.00	47.00			

Hawthorn Nonsolar

Groups	*Count*	*Sum*	*Average*	*Variance*
Mycorrhizal	21.00	1183.00	56.33	236.13
Non-mycorrhizal	21.00	917.00	43.67	236.13

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	1684.67	1.00	1684.67	7.13	0.01
Within Groups	9445.33	40.00	236.13		
Total	11130.00	41.00			

Table 3. *Basic statistics and t-test results for the two species (*Prunus avium, Crataegus monogyna*) known to host arbuscular mycorrhizal fungi*

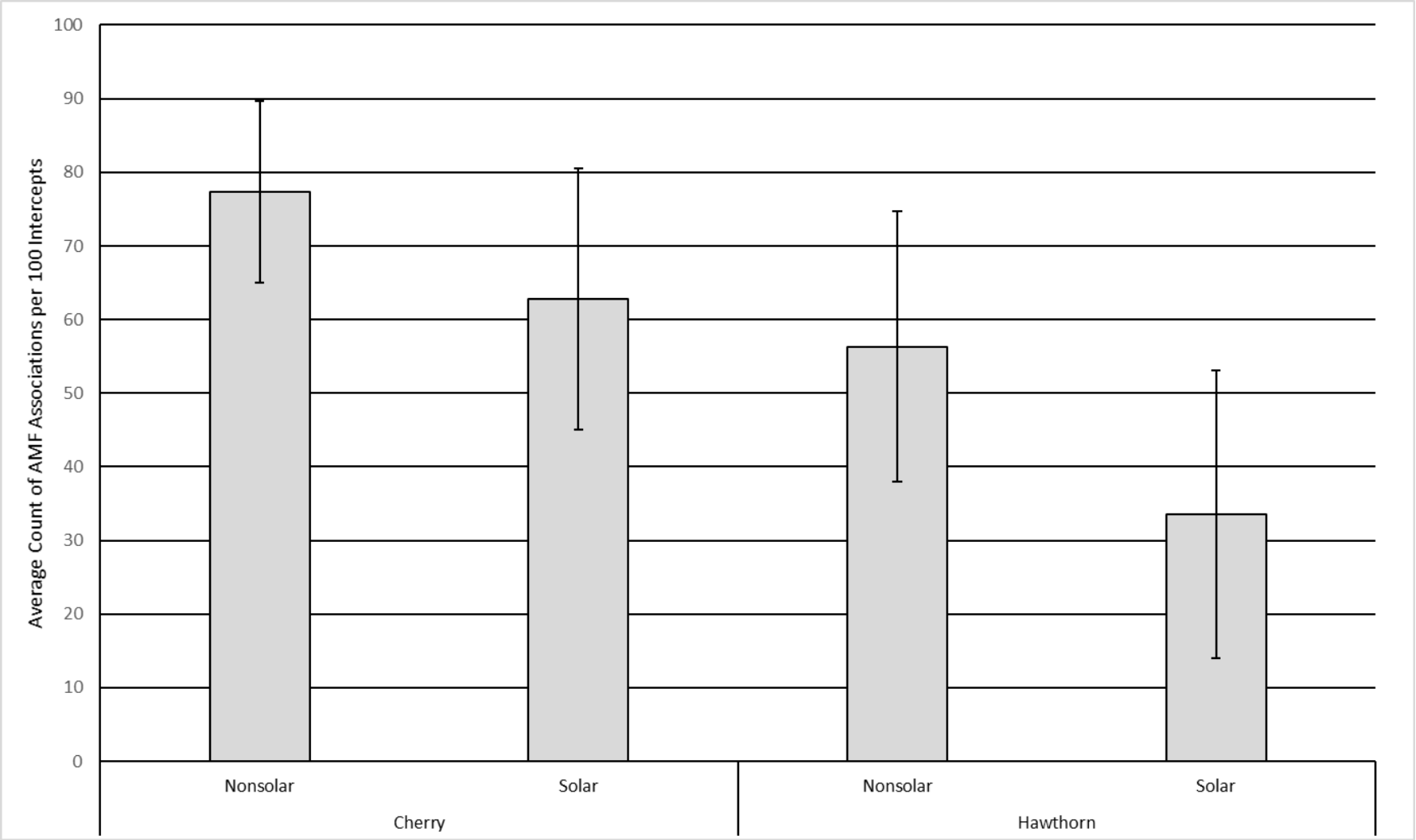

Fig. 5. *Mean mycorrhizae intercept count per 100 roots in hawthorn and Mazzard cherry. Nonsolarized and solarized treatments were statistically different ($P < 0.05$). Error bars represent standard deviations.*

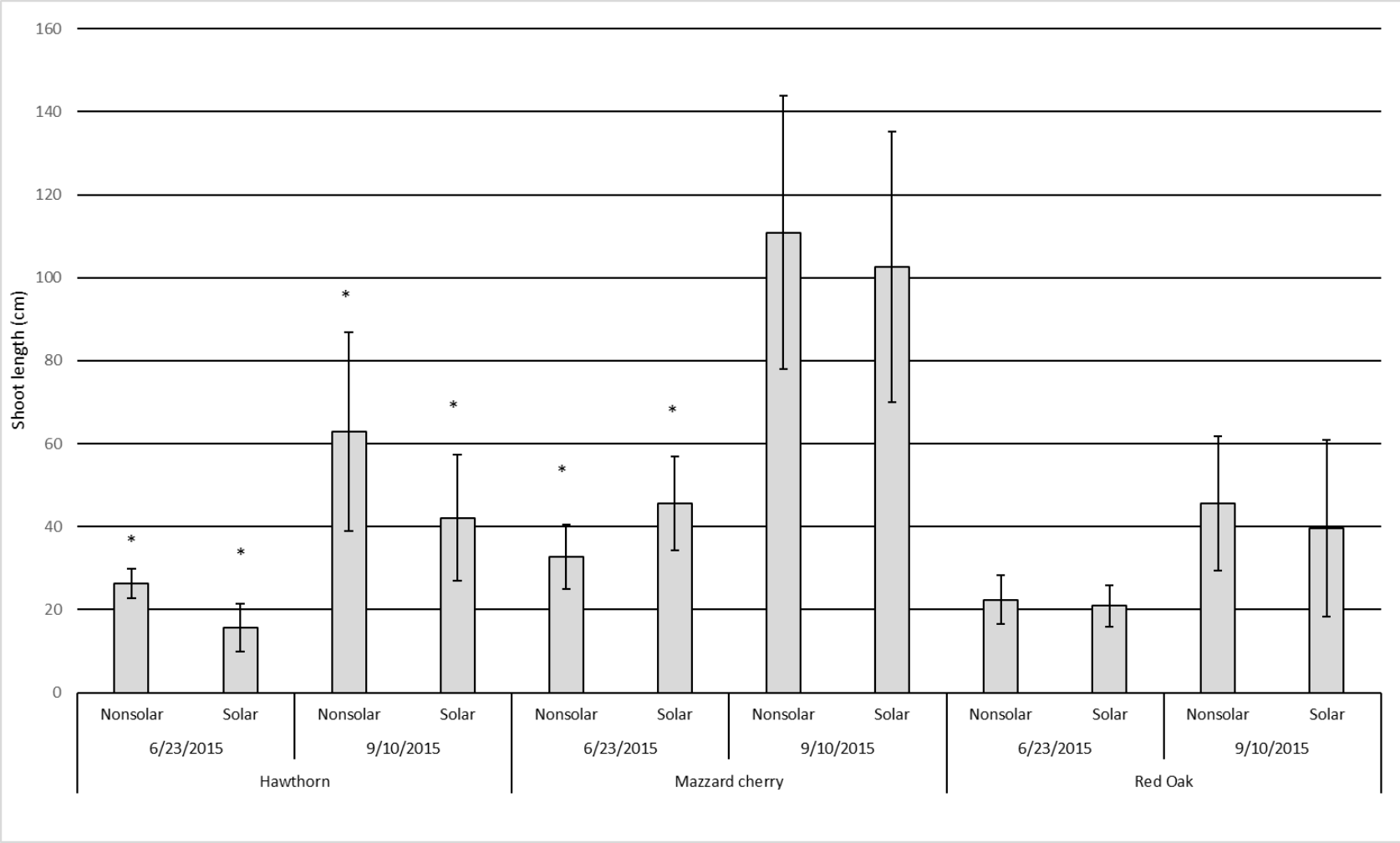

Fig. 6 *Shoot length for all three species on both collection dates. Starred bars (*) showed significant differences between nonsolarized and solarized treatments ($P < 0.05$). Error bars represent standard deviations.*

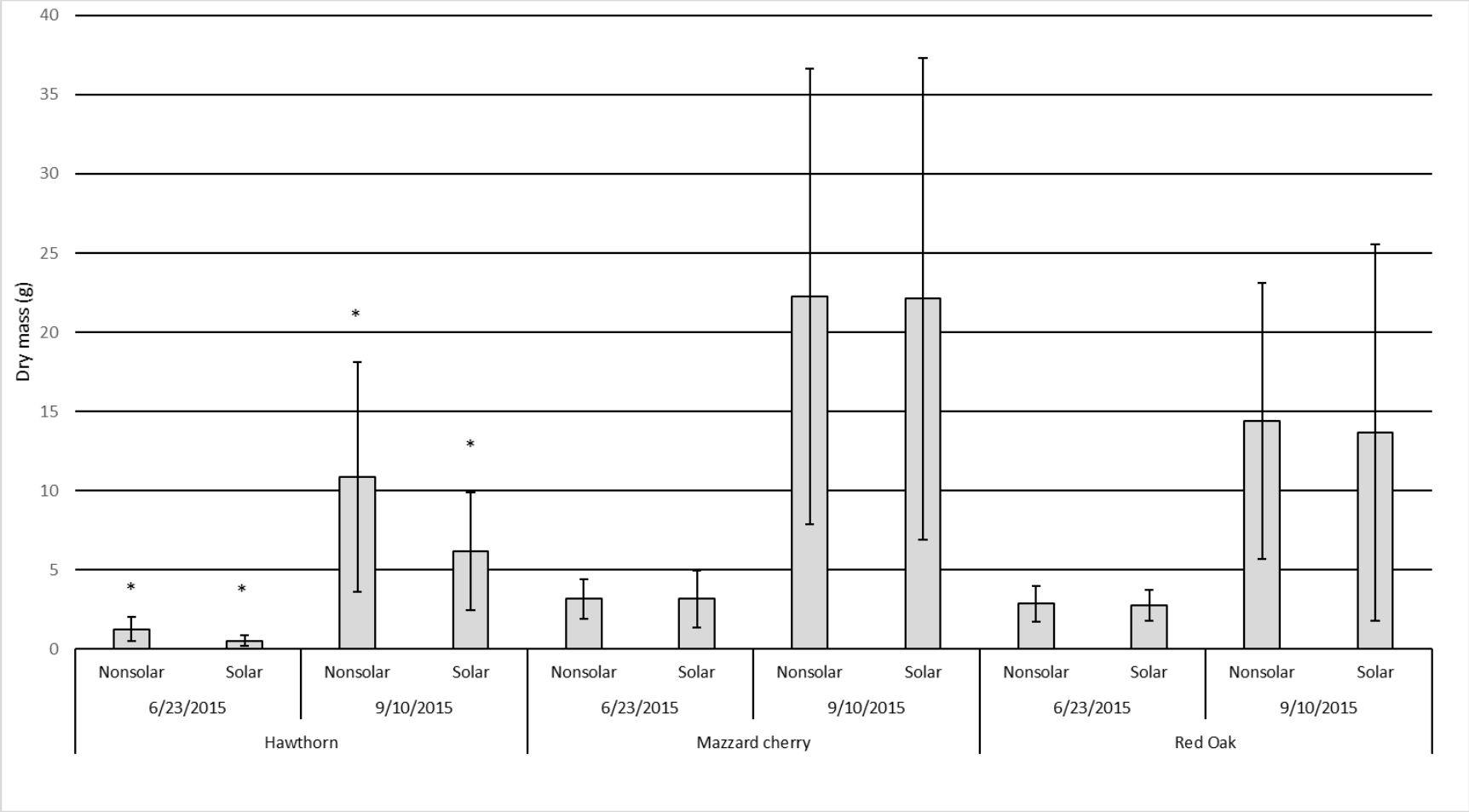

Fig. 7 *Shoot biomass for all three species on both collection dates. Starred bars (*) showed significant differences between nonsolarized and solarized treatments ($P < 0.05$). Error bars represent standard deviations.*

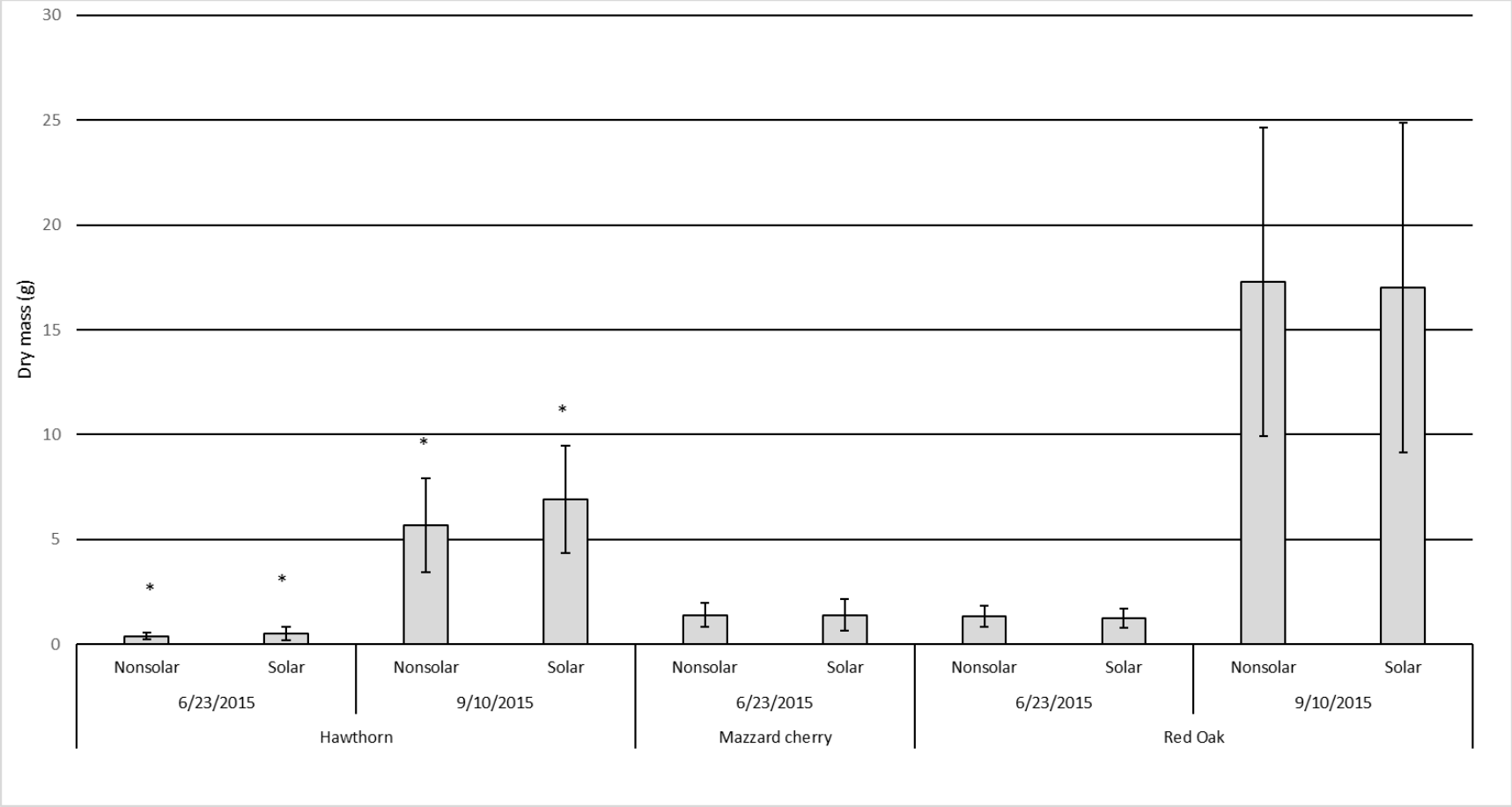

Fig. 8 *Root biomass for all three species on both collection dates. Note that there were no data collected for Mazzard cherry roots on 9/10/15. Starred bars (*) showed significant differences between nonsolarized and solarized treatments ($P < 0.05$). Error bars represent standard deviations.*