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Final Report

Assessing the Influence of Irrigation and Treeshelters on Three California Native Oak Species

I. Irrigation Effects on Growth of Container Stock

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Introduction

Although native oaks are considered to be highly desirable species in California landscapes, oak populations have declined in both wildland and urban areas over the past century (Pavlik et al 1992). In the last 16 years, however, substantial efforts have been made to restore populations in wildland areas, and new stands have been established (Standiford 1999; McCreary 1993; Swiecki and Bernhardt 1993). In urban areas, however, many mature oaks have been removed for development, health, or structural reasons and replaced with non-native species. As a result, populations have continued to decline.

Often, native oaks are replaced with non-native species because they have been characterized as being slow-growing: they are viewed as requiring much more time to achieve a desirable size than "fast-growing" landscape species. This characterization likely resulted from observations of the growth of oaks in their native habitat, however, and may not be an accurate assessment of their actual performance in urban landscapes. Since many urban landscapes in California are irrigated, and the growth rate of many woody species is enhanced by irrigation, it was hypothesized that the growth rate of native oaks may be enhanced by irrigation.

This study was initiated to assess the influence of irrigation on top and root growth of three California native oak species. Specifically, our objectives were three-fold: 1) to assess the influence of irrigation on trunk diameter growth of container-grown stock, 2) to quantify shoot-to-root ratios, and 3) to describe root distribution. Since oaks are noted for investing a considerable amount of biomass in root development, it was considered important to evaluate irrigation effects on both above and below ground portions of the trees. Typically, most studies assess growth response by measuring top growth only. However, evidence indicating that top growth can be enhanced at the expense of root growth (Burger 1996) adds emphasis to the need to evaluate both tops and roots. This information can be used to more accurately develop performance expectations for native oaks in irrigated urban landscapes.

Methods

This study was conducted at the University of California Research and Extension Center in Santa Clara, CA, from spring 1997 to fall 2001. Prior to planting, a field plot measuring 100-ft (32.8 m) wide and 125-ft (41 m) long was cultivated approximately 2.5-ft (14.3 m) deep to create uniform root zone soil conditions. Container stock (5 gallon, 19 liter) of three species of California native oak were selected for uniformity of size, health, and vigor from nurseries in the San Francisco Bay area. Species included *Quercus lobata* (valley oak), *Q. agrifolia* (coast live oak), and *Q. douglasii* (blue oak). All plants were hand watered biweekly for 3 months after planting.

Trees were spaced 10 ft (3.28 m) apart in rows, with rows spaced 10 ft (3.28 m) apart. Randomized complete blocks were established with 3 irrigation treatments for each species per block. Eight replicates for each treatment and species gave a total of 72 trees in the study plot (fig. 1).

Fig. 1. In 1997, container stock of coast live oak, valley oak, and blue oak were planted at the University of California Research and Extension Center in Santa Clara, CA. Irrigation treatments (0, 0.25, and 0.5 ETo) were initiated after a one-year establishment period. Here, plot layout and irrigation lines are shown.

Irrigation treatments were established as fractions of reference evapotranspiration (ET_0): 0.25 ET_0, 0.50 ET_0, and 0 (control) (Costello and Jones, 2000). Reference evapotranspiration was measured from a California Irrigation Management Information System (CIMIS) station located adjacent to the study plot.

During the first year of the study, all plants received 1.0 ET_0. This ensured the survival of all trees and allowed for a root establishment period (standard practice for container stock) (Harris *et al*, 2003). Irrigation treatments were initiated in the second year (1998) and continued for the duration of the study. On average, 0.25 ETo treatments received 3.5 gallons (13.3 liters) per week and 0.50 ETo treatments received 7.0 gallons (26.6 liters) per week.

Irrigation water was supplied using a Netafim Techline pressure compensating drip system (1/2-in polyethylene tubing). In-line emitters were placed in a circle within the canopy perimeter (drip line) of each tree, with 4 emitters per tree. In 1999, an additional line of emitters was added to the outside of the initial line to provide water to the enlarging root system (fig. 2). Each emitter supplied 3.8 liters (1 gallon) per hour. To monitor total water supplied to all plants in each irrigation treatment, flow meters (Neptune 5/8") were installed in each main line. This provided a means of ensuring that 0.50 ET_0 treatments were actually receiving two times the amount of water of 0.25 ET_0 treatments. Water supply was controlled with a 6-station timer (Hardie Rain Dial), set to irrigate 0.25 and 0.50 ET_0 treatments once and twice per week, respectively. Soil moisture sensors (Irrometer Corp.) were installed 6- and 12-in (15.3 and 30.5 cm) deep within the irrigated zone of plants at 7 locations across the plot. Sensors were used to monitor water application uniformity and assess moisture depletion between irrigations.

Fig. 2. During the second year after planting, an outer ring of drip emitters was added to irrigation treatments to deliver water to the expanded root zone.

Tree Measurements

Trunk diameter was measured annually for all trees at 6-in (15.3 cm) above ground line. Plant height was recorded, but was not used to assess treatment effects due to variability in tree form.

In summer 2001, the root system of select trees was excavated to measure root mass and distribution (fig. 3). Three trees from each irrigation treatment were measured for coast live oak, while only one tree from each treatment was measured for blue oak. Due to time and budget constraints, root systems of valley oak were not measured.

Fig. 3. After 4 years, root systems of coast live oak and blue oak were fully excavated using a pneumatic excavation tool (Airspade®), backhoe, and jackhammer. Here, the Airspade is being used to remove soil from roots.

Excavations were performed using a pneumatic excavation tool (Airspade®), backhoe, and jackhammer. Trenches were dug 6-ft (2 m) deep and 5-ft (1.6 m) from the trunk on two or three sides of excavation trees. Trenches were used as a receptacle for soil removed from roots. Pnuematic excavation tools have been found to be quite useful for root crown and root zone excavations (Smiley, 2001) primarily because they cause little damage to root systems: only very small diameter roots (<0.8 in, 2 mm) are damaged, while larger roots remain intact.

Following excavation, intact root systems were removed and stored for measurement. Root distribution was measured by suspending the excavated root system from a greenhouse roof and leveling it with elastic ties (to establish ground line) (fig. 6). The diameter of all roots at 6, 24, and 48-in (15.3, 60.1, and 122 cm) depths were measured and their distance from the root system center point (a vertical axis extended down from the trunk) was recorded. This gave an assessment of the amount of root mass at each depth and lateral distance from the trunk. Diameter of all roots was combined into a cumulative value for each of 3 depths (6, 24, and 48 in; 15.3, 60.1, and 122 cm) and four distance ranges (0-12, 13-24, 25-36, and 37-48 in; 0-30.5, 31-61, 62-91, and 92-122 cm). Cumulative root diameter (CDR) was used to assess irrigation treatment effects on root distribution. To establish root-to-shoot ratios, root systems and tree tops (trunk, branches, and leaves) were air dried for two months and then weighed.

Results and Discussion

All trees survived and grew for the duration of the study. Blue oaks were affected by powdery mildew during the summer months, but no trees were severely damaged. Irrigation treatment effects on trunk diameter are reported for all species, while shoot and root weights, root to shoot ratio, and root distribution are reported for coast live oak and blue oak.

Trunk Diameter

Trunk diameter growth was significantly greater for coast live oak than valley oak or blue oak (Table 1). Valley oak growth was significantly greater than blue oak. Trunk diameter in 2001 was 11-fold greater than that in 1997 for coast live oak, 7.5-fold greater for valley oak, and 4.5-fold greater for blue oak.

Table 1. Mean trunk diameter of coast live oak (CLO), valley oak (VO), and blue oak (BO) from 1997 to 2001 for 3 irrigation treatments (0 ETo, 0.25 ETo, and 0.5 ETo), and mean height in 2001. D = diameter (mm); Ht = height (cm). Diameter values with different letters are significantly different (Fisher's least significant difference test, p=0.05).

Species	Irrig. Trt.	D 97	D 98	D 99	D 00	D01	Ht 01
Coast live oak	0	13a	40a	59a	105a	139a	341
	0.25	13a	46a	71a	121a	152a	325
	0.5	13a	45a	68a	116a	140a	351
Valley oak	0	12b	28b	40b	67b	88b	326
	0.25	12b	24b	36b	62b	83b	388
	0.5	11b	27b	39b	66b	85b	378
Blue oak	0	11b	18c	24c	37c	45c	216
	0.25	11b	22c	29c	45c	54c	219
	0.5	10b	17c	24c	37c	44c	214

For all three species, no significant differences in mean trunk diameter resulted from irrigation treatments (Table 1). Diameter differences were small and not consistent for irrigation levels. For example, greatest trunk diameter (2001) for coast live oak and blue oak was found for 0.25 ETo, while trunk diameter for 0.5 ETo and 0 ETo treatments were virtually the same. For valley oak, trunk diameter values for all treatments were within 5% of one another.

A lack of response to irrigation treatments by these species was attributed to several factors. First, rainfall during the first year of the study was 50% greater than the 10-year average for the plot location (Table 2). Even though rainfall in subsequent years was 10 to 26% below normal (for the 10-year period), high soil moisture level during the first year of establishment may have been sufficient to moderate potential irrigation effects in subsequent years.

Table 2. Precipitation at study plot for the period 0ct - May from 1997 to 2001.

Date	Precipitation (cm)
1997-1998	59.7
1998-1999	29.1
1999-2000	35.6
2000-2001	32.8
10-year mean for Oct-May	39.6

Second, all three species were found to develop relatively deep root systems in the first year after planting, and this pattern continued for the duration of the study (figs. 4 & 5). In July, 1998, excavations of trees planted adjacent to the study plot (for demonstration purposes) showed that after approximately one year roots had developed to a depth of 2 to 3 ft (0.66 and 0.98 m). In addition, an assessment of root distribution of coast live oak and blue oak after 4 years (Table 4) found that root mass was greatest at depths between 24 and 48 in (60.1 and 122 cm). Generally, roots were found to have developed between 30^0 and 80^0 from horizontal. This finding is contrary to a previous (unrelated) study of root distribution of Raywood ash (*Fraxinus angustifolia* 'Raywood') and Lombardy poplar (*Populus nigra* 'Italica') at the same field station and in equivalent soil conditions (Costello et al 1997). Roots of these species were found to develop largely in a horizontal plane (90^0 from vertical) near the soil surface (0–6 in depth). These observations and results indicate that within a year after planting test oaks were capable of developing relatively deep root systems.

Fig. 4 (left). One year after planting, roots of container stock showed a strong vertical orientation. Here, several roots of coast live oak (painted white) developed below the 2-ft depth.

Fig. 5 (right). Two years after planting, root mass of coast live oak had increased substantially. Here, several roots are 3 to 4 feet deep.

Third, soil characteristics at the study plot were considered to be nonlimiting to root development. Chemical and physical properties evaluated prior to planting were found to be in a range considered not limiting for most species (Craul 1999, Costello et al 2003).

These three factors, above normal rainfall (1997-98), relatively deep root development, and soil characteristics not limiting for most species, collectively may have contributed to the early establishment of the test species, resulting in a lack of growth response to irrigation. In other words, after the first year, all three species developed sufficiently large root systems that were sufficiently deep to extract water to meet developmental needs. Accordingly, soil moisture was not limiting to growth and supplemental water supplied by irrigation had little or no effect on diameter growth.

The findings of this study are consistent with the results of a concurrent study evaluating irrigation effects on acorn stock of coast live oak, valley oak, and blue oak (see section

II). Acorns planted at the same location, and in a plot adjacent to the container stock plot, were irrigated at 0, 0.25, and 0.5 ETo. Trunk diameter and height were measured over the same 4-year period. Similar to this study, no significant irrigation effects were found for acorn stock for any year of the study.

Height

After 4 years, average height of valley oak was 12 ft (3.9 m), while that of coast live oak was 11 ft (3.6 m), and blue oak was 7 ft (2.3 m) (Table 1). Little difference in height was found among irrigation treatments. Since height is not a good measure of plant growth, however, treatment effects were not analyzed statistically.

Shoot-to-Root Ratio

Shoot-to-root ratios for coast live oak (calculated from dry weights) ranged from 2.3 to 3.1 (Table 3). Mean ratio was 2.6, indicating that (on average) coast live oak develops 2.6 times more biomass above ground than below ground. Shoot-to-root ratios for blue oak ranged from 0.8 to 1.1, with a mean value of 1.0 (Table 3). This ratio suggests that blue oak develops approximately the same amount of biomass above ground and below ground. These results indicate that the relative amounts of biomass partitioned to above and below ground parts are not equivalent for blue oak and coast live oak.

Table 3. Mean weight of shoots and roots (kg), and shoot to root ratios for coast live oak for 3 irrigation treatments (0 ETo, 0.25 ETo, and 0.5 ETo). Blue oak values are for one tree only per treatment.

Species	Irrigation Trt.	Shoot wt. (kg)	Root wt. (kg)	Shoot/Root
Coast live oak	0	25.8	11.4	2.3
	0.25	25.0	10.5	2.4
	0.5	38.7	12.6	3.1
	mean	29.8	11.5	2.6
Blue oak	0	2.1	2.5	0.8
	0.25	2.7	2.5	1.1
	0.5	2.3	2.3	1.0
	mean	2.4	2.4	1.0

Root Distribution

At the 6-inch (15.2 cm) depth, cumulative root diameter (CRD) and root number for coast live oak were greatest within 12 in (30.5 cm) of the trunk for all irrigation treatments (Table 4). This result was to be expected since this is the zone where roots arise (root crown) and are most concentrated. At distances beyond 12 in (30.5 cm), however, substantially less root development was found. From 13 to 24 in (31-61cm), cumulative diameter declined 57 to 94% (depending on irrigation treatment), while root number declined 47 to 86%. Very few roots were found from 25 to 36 in (62-91cm), while no roots occurred beyond 36 in (91 cm).

Table 4. Mean cumulative root diameter (mm) and mean number of roots for coast live oak (Q. agrifolia) at 3 depths (6, 24, and 48 in) and 4 distances from the trunk. Values for blue oak (Q. douglasii) are for one tree for each irrigation treatment.

Species	Irrig. Trt	Depth (in)	Distance from trunk							
			0 - 12 in		13 - 24 in		25 - 36 in		37 - 48 in	
			Cum. Dia.	No. roots	Cum. Dia.	No. roots	Cum. Dia.	No. roots	Cum. Dia.	No. roots
Coast live oak	0	6	434	16.3	28	2.3	9	1.6	0	0
	0	24	89	9.3	217	24.3	140	15.3	91	8.6
	0	48	36	1.3	30	3.3	64	7.3	65	9.3
	0.25	6	411	23	51	3.6	6	0.33	0	0
	0.25	24	103	10	149	17	106	16	85	8.3
	0.25	48	20	2.6	46	6.3	36	4.3	48	8
	0.5	6	336	17	147	9	7	0.33	0	0
	0.5	24	50	4.3	121	11	101	14	96	13
	0.5	48	30	3	37	4	35	5	37	5.6
Blue oak	0	6	201	21	15	0	0	0	0	0
	0	24	5.5	2	112.6	23	26.7	4	1.4	1
	0	48	3.3	2	7	3	3.6	1	4.2	3
	0.25	6	249	23	0	0	0	0	0	0
	0.25	24	117	22	15.4	3	0	0	0	0
	0.25	48	0	0	0	0	0	0	0	0
	0.5	6	201	25	17.7	2	0	0	0	0
	0.5	24	27.7	5	24.1	4	0	0	0	0
	0.5	48	5	1	3.8	1	7.5	2	0	0

At the 24-in (61 cm) depth, there was greater root mass at all distances relative to the 6-in (15.2 cm) depth, except for the 0-12-in (0-30.5 cm) distance where a 75 to 84% reduction in CRD and 43 to 75% reduction in root number was found. From 13 to 24 in (31-61 cm), however, CRD increased 45 to 144%, and root number increased 70 to 161% (across irrigation treatments). CRD and root number then declined from 25 to 48 in (62-91 cm). Compared to the 6-in (15.2 cm) depth for this distance, however, there was substantially greater root mass at the 24-in (30.5 cm) depth.

Roots were found at all distances from the trunk at the 48-in (91 cm) depth. Both CRD and root number declined relative to the 24-in (30.5 cm) depth at all distances, but both values were substantially larger than those found between 25 and 48 in (62-91 cm) at the 6-in (15.2 cm) depth. Generally, CRD and root number in the 25 to 48-in (62-122 cm) zone was equivalent to or greater than that found in the 0 to 24-in (0-30.5 cm) zone. Mean root diameter in the 37 to 48-in (94-122 cm) zone ranged from 0.24 to 0.28 in (6-7 mm) across irrigation treatments.

Collectively, root distribution measurements indicate that greatest root mass (CRD and root number) occurred in a zone well below the horizontal axis (soil line). This zone was estimated to be between 30^0 and 80^0 from the horizontal, indicating that root development occurred with a stronger vertical than horizontal orientation (fig. 6).

Fig. 6. Excavated root systems were suspended and leveled to measure root distribution. Measurements were taken at 3 depths (6, 24, and 48 inches) and at 4 distances from the trunk (0-12, 13-24, 25-36, and 37-48 inches). Many roots of this coast live oak show a strong vertical orientation.

Blue oak root distribution followed a pattern similar to that of coast live oak, but root systems were smaller and not as widely spread (Table 4). Roots were found to develop to the 48-in (91 cm) depth, but most were within a distance of 24 in (30.5 cm) from the trunk. Generally, there was a stronger downward orientation to root growth than that found in coast live oak.

Conclusions

Several key findings are notable. First, irrigation did not enhance trunk diameter growth of coast live oak, valley oak, or blue oak. After a one-year establishment period, each of these species was found to grow at the same rate without irrigation as with irrigation.

Second, trunk diameter growth was significantly different for the 3 oak species: coast live oak was largest, blue oak smallest, and valley oak in between.

Third, coast live oak apportions approximately 2.5 times more biomass to shoots than roots. Blue oak apportions approximately equal amounts of biomass to shoots and roots.

Fourth, roots of coast live oak and blue oak developed with a relatively strong vertical orientation. Root mass was greatest in a zone approximately 30^0 to 80^0 from horizontal. Roots of both species were found 48 in (122 cm) deep, and some roots grew deeper.

It needs to be emphasized that these findings are linked to site and study conditions. Specifically, trees were grown in a well-cultivated and relatively deep soil with favorable soil moisture levels during the first year (from irrigation and above normal rainfall).

Similar results may not be found in soils that are limiting to root development (e.g., high bulk density, perched water table, salts, etc.) and/or soils with low soil moisture conditions during the first year.

These findings indicate that container stock of coast live oak, valley oak, and blue oak can be grown equally well in landscapes without irrigation as with irrigation (under the conditions described). Even though their growth is not enhanced by irrigation, coast live oak and valley oak can achieve heights comparable to that of many landscape species (11 and 12 ft or 3.6 and 4 m, respectively, in 4 years after planting), and both species should be considered to be particularly suitable for water-conserving landscapes. Blue oak is highly suitable for water-conserving landscapes as well, but having a growth rate less than coast live oak and valley oak, it may have more limited landscape utility.

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Introduction

During the past two decades there has been increasing public concern about conservation and management of native oaks in California. Poor natural regeneration of several oak species has been repeatedly identified as a problem. Until recently, however, relatively little was known or understood about the biology of California oaks in general or regeneration processes in particular. Concerns about regeneration have led to a number of studies aimed at developing successful procedures for artificial regeneration of native oaks (Adams and others 1991, McCreary 1989). However, most of this research has been conducted on relatively harsh rangeland sites, such as Sierra Foothill and Hopland Research and Extension Centers (SFREC and HREC). Consequently, there is little information about the best procedures for establishing oaks in landscape settings where opportunities for more intensive management are possible.

One device that has shown particular promise for establishing oaks on rangelands is the treeshelter (Costello et al 1996, McCreary and Tecklin 1997, Tecklin et al 1997). These are double-walled translucent tubes that protect seedlings from a number of damaging animals. They also stimulate aboveground growth by changing the environment seedlings are exposed to, including higher levels of CO_2, higher temperatures, and increased humidity (Potter 1991). However, some feel these devices may produce “unnatural” plants that are ill-adapted to survive after the shelters are removed. This is because plants in treeshelters tend to grow tall and thin and may be unable to stand upright when shelters are removed. It has also been suggested that treeshelters may cause a preferential allocation of photosynthate to shoots. As a result of such carbon allocation, plants may be out of balance and not develop sufficiently large root systems to support their tops. It is not known, however, if such imbalances occur or how long they might last.

Finally, most research on oak regeneration in California has been with blue oak. This species has been identified as having poor natural regeneration and since it is widely distributed, there has been great interest in determining why regeneration is inadequate and how to overcome this problem. However, in urban or landscape settings, other native oak species may be preferable for planting because they have the potential to establish more quickly and grow faster.

This research project was designed to evaluate the performance of three species of native oaks planted in a horticultural setting, provided different levels of irrigation, and either protected with treeshelters or left unprotected. Annual height and diameter growth were monitored for 4 years and total root weight, total shoot weight and shoot/root ratio were measured at the end of the study.

Methods

This study was conducted at Bay Area Research and Extension Center (BAREC) in Santa Clara. This Center offers a much different environment than SFREC or HREC since it has deep, uniform, agricultural soils, providing an opportunity for high levels of management. The field site was tilled and all weeds removed prior to planting. The soil, which is over a meter deep, is classified as a loam (47% sand, 38% silt, and 15% clay).

In January 1997, pregerminated acorns of blue oak *(Quercus douglasi*i), valley oak *(Q. lobat*a) and coast live oak *(Q. agrifoli*a) were planted in a field plot consisting of 4 blocks, each with 72 planting locations. Each block contained three irrigation treatment groups (24 seedlings). Irrigation treatments were 0.50 ETo (reference evapotranspiration), 0.25 ETo, and 0 ETo (control). Reference evapotranspiration was determined by a CIMIS (California Irrigation Management Information System) station located at BAREC. During the middle of summer ETo averages about 4 cm per week at BAREC.

All seedlings were irrigated during the first growing season with sufficient irrigation to ensure establishment, but no irrigation was provided to controls thereafter. The pressure compensating drip irrigation system provided water to an area approximately 20 cm by 20 cm around each planting location once a week through 3.6 liters-per-hour drip emitters. Irrigation continued until the fall rainy period. Irrigation was initiated in subsequent years (1998 – 2001) in the summer and continued until there was 5 cm of rain in the fall. For the 0.25 ETo treatment, 3.6 liters per week were supplied, and 7.2 liters per week for the 0.50 ETo treatment.

Within each of the 24-seedling irrigation plots, acorns were spaced 1.2-m apart. Each plot was separated from other plots by 2.4 m to ensure that irrigation treatments did not influence seedlings in adjacent plots, and a buffer row of seedlings was planted around the entire perimeter of the study area. Within each irrigation plot were three pairs of four-seedling rows. Each pair was randomly assigned to be planted with acorns from one of the three species. In addition, one of these rows from each pair was randomly assigned to have a 1.2-m treeshelter placed over emerging seedlings, while seedlings in the other row were left unprotected. All acorns were planted within a 2-day period.

Height and Diameter Measurements

Seedlings began to emerge in March 1997. At the end of the year, the height of each surviving seedling was measured and recorded (fig 1). Height was the distance from the base of the seedling to the end of the longest shoot held straight. At the end of 1998 and 1999, the height, as well as the diameter, of each seedling was measured. Diameter measurements were taken at the base of each seedling, approximately 2 cm above the ground.

Fig. 1. Acorns were planted with and without treeshelters and at 3 levels of irrigation (0, 0.25, and 0.50 ETo). Here, coast live oak, valley oak, and blue oak are shown 8 months after planting. Note that one tree (on right) has grown above the top of the treeshelter.

Final field assessments were made in mid-2001. Height was measured in May. In contrast to previous measurements where the longest terminals were measured, by mid-2001, many of the coast live oak trees were so tall that it was not possible to measure them this way. Therefore heights for this species were recorded as the distance from the base of the tree to the tallest portion of the plant. Diameters for all species were measured as before.

Root Excavation and Measurements

An objective of this study was to determine how shelters and irrigation affect root development and, in particular, whether treeshelters increase shoot growth at the expense of root growth (figs. 2 & 3). To determine this, we excavated, weighed, and measured root systems. However, since excavations are difficult, expensive, and time consuming, we excavated only a sub-sample of saplings in the study. We excavated all surviving saplings in one of the four blocks. Unfortunately, we were also constrained by the fact that one of the species, coast live oak, is susceptible to a new and potentially devastating disease called Sudden Oak Death, caused by the pathogen *Phytophthora ramoru*m. Since BAREC is located in one of the infected counties, there was a quarantine on movement of coast live oak plant parts outside the county.

Fig. 2. All species formed tap roots in the first year. Here, the tap root of a blue oak developed almost 1-m deep after 8 months.

Since our root evaluation procedures required us to take all of the harvested trees back to Sierra Foothill Research and Extension Center in Yuba County to dissect, measure and weigh, we elected to concentrate our root excavation and assessment on blue oak and valley oak and not evaluate the roots of coast live oak.

Fig. 3. Acorn stock with and without treeshelters developed similar amounts of biomass. Here, the root system of blue oak with a treeshelter (on left) is shown next to the root system of blue oak without a treeshelter (after 2 years). The pit is approximately 4-ft deep.

A backhoe was used excavate a 1.2-m deep hole on either side of each sapling, approximately 1.2 to 1.8-m from the trunk. The narrow bucket of the backhoe was used to carefully reach into the root zone and loosen the soil. The trunk of the sapling was then secured to a chain, which was hooked to the bucket of the backhoe. The bucket was rocked back and forth to loosen the soil in the rooting zone, and finally the chain was raised slowly, lifting the sapling and pulling it out of the ground. This worked quite well and seemed to provide a good, though not complete, recovery of roots. We estimated that approximately 10 percent of the roots was left behind, based on where and how thick some of the roots were that broke off. However it was not possible to accurately estimate how many of the finer roots were not recovered. In several cases, more roots broke and remained in the soil than we felt were acceptable; we excluded these from our sample.

Excavated trees were brought to SFREC, air dried in a warehouse for approximately two weeks, and then cut at root crown (the ground line), and separated into shoots and roots. These were placed in a drying oven for 5 days at 70°C. Prior to drying, all woody material was cut up into 10 to 15-cm segments. Dry weights for shoots and roots for each tree were recorded and shoot/root ratios were calculated. Prior to drying and weighing, the diameters of the roots at various depths were also measured, and the roots were separated into various fractions (i.e. upper tap root, lower tap root, lateral roots) for weighing.

Statistical Analysis

Field data including survival, height and diameter were analyzed for a doubly nested, randomized block design, with irrigation levels as main plots, species as sub-plots, and protection treatments as sub-sub-plots. The data for these analyses were averages of the four-seedling rows within each block, irrigation treatment, species and type of protection (treeshelter or control).

We did not have enough observations to statistically analyze the shoot and root weight data as above, since only 31 sample trees were recovered with useable, excavated roots. We therefore analyzed shoot weights, root weights and shoot/root ratios for treatment effects using one-way analyses of variance.

Results

Survival

There were no significant differences in survival among any treatments during any year of the study. Average survival at the end of the first year (1997) was 82 percent, but remained fairly constant thereafter, falling to 79 percent by the last evaluation in 2001 (table 1). One factor that appeared to contribute to initial mortality was that in some treeshelters rainwater did not drain adequately and some tubes filled several inches with water. When we observed this, we made holes in the bottoms of the shelters to drain the water, but there was probably some acorn mortality due to poor drainage.

Table 1. Survival (pct) of acorn plantings for different species and treatments between 1997 and 2001.

	Survival '97	Survival '98	Survival '99	Survival '01
Species				
Blue Oak	75	75	75	74
Valley Oak	82	81	81	80
Coast Live Oak	88	84	88	83
Protection				
Treeshelters	81	80	80	80
Control	82	81	81	81
Irrigation				
No Water	78	77	78	76
0.25 Evapotranspiration.	85	84	85	83
0.50 Evapotranspiration.	81	79	80	78

1 There were no significant differences in survival in any year among species, protection treatments or irrigation treatments. Some survival percentages increased between 1998 and 1999 because of resprouting from apparently dead tops.

Height

Significant differences in height were found among species in each year of the study. During the first and second years (1997 and 1998), valley oaks and coast live oaks were significantly taller than blue oaks, but not different from each other (table 2). By the last two years, there were significant differences between all three species, with coast live oaks the tallest, valley oaks next, and blue oaks the shortest.
Trees in treeshelters were significantly taller than trees without shelters in every year of the study. However, on a percentage basis, these differences tended to decline over time. There were no significant differences in height among irrigation treatments during any year of the study.

Table 2. Average height (cm) for different species and treatments between 1997 and 2001.

	Height '97	Height '98	Height '99	Height '01
Species				
Blue Oak	41 a	99 a	171 a	204 a
Valley Oak	91 b	156 b	213 b	258 b
Coast Live Oak	75 b	159 b	256 c	329 c
Protection				
Treeshelters	89 a	167 a	240 a	288 a
Control	50 b	108 b	187 b	240 b
Irrigation				
No Water	63	127	200	244
0.25 Evapotranspiration	67	141	211	269
0.50 Evapotranspiration	77	145	229	279

1 Within treatments (irrigation and protection) and years, heights with different letters are significantly different by a Fisher's Protected Least Significant Difference (LSD) Test.

There were no significant differences in any year among irrigation treatments.

Diameter

Differences in diameter among species followed a pattern similar to that for height. For every annual evaluation, there were significant differences among species with coast live oaks having the largest diameters, followed by valley oaks and blue oaks (table 3).

Table 3. Average diameter (mm) for different species and treatments between 1997 and 2001.

	Diameter '98	Diameter '99	Diameter '01
Species			
Blue Oak	11.5 a	19.9 a	34.1 a
Valley Oak	16.1 b	25.1 b	42.0 b
Coast Live Oak	22.7 c	42.3 c	77.1 c
Protection			
Treeshelters	14.9 a	26.8 a	46.9 a
Control	18.6 b	31.4 b	55.2 b
Irrigation			
No Water	15.5	27.0	45.1
0.25 Evapotranspiration	16.5	28.9	52.1
0.50 Evapotranspiration	18.2	31.4	54.6

1 Within treatments (irrigation and protection) and years, diameters with different letters are significantly different by a Fisher's Protected Least Significant Difference (LSD) Test. There were no significant differences in any year among irrigation treatments

Each year there were also significant differences between trees protected with treeshelters and those unprotected. However, in contrast to height, treeshelters produced plants with smaller stem diameters. As with all other variables, there were no significant differences in stem diameter among irrigation treatments.

Shoot and Root Weights

Valley oaks grew considerably larger than the blue oaks, and consequently, had significantly greater shoot and root dry weights. However there were no significant differences in shoot/root ratio between species. In addition, no significant differences in shoot dry weight, root dry weight or shoot/root ratio between irrigation or protection treatments were found (table 4).

Interactions

There were several significant interactions in the analyses of height and diameter. In most cases this was because coast live oak had less of an increase in height for trees in treeshelters than the other two species. This species also had a greater decrease in diameter for trees in treeshelters. The only other significant interaction was between irrigation and species for the final assessment of diameter:

the rankings of species were the same for each irrigation treatment, but the relative values were different.

Table 4. Average shoot weights, root weights and shoot/root ratios for saplings harvested in July, 2001.

	Shoot wt. (gm)	Root wt. (gm)	Shoot/Root Ratio
Species			
Blue Oak	945 a	742 a	1.32
Valley Oak	2100 b	1393 b	1.55
Protection			
Treeshelters	1451	987	1.52
Control	1577	1154	1.31
Irrigation			
No Water	1901	1316	1.27
0.25 Evapotranspiration	1445	953	1.60
0.50 Evapotranspiration	1160	947	1.30

1 There were significant differences in shoot weight and root weight between valley oak and blue oak saplings by a Fisher's Protected Least Significant Difference (LSD) Test. There were no other significant differences.

Discussion

In several studies treeshelters have been found to increase the growth of native California oaks (Costello and others 1996, McCreary and Tecklin 1997, Tecklin and others 1997). In two trials with coast live oak and valley oak, however, Burger and others (1996 and 1997) reported that while plants in treeshelters initially grew taller, by the second year there were no significant differences in height compared with unsheltered plants. Burger and others (1992) also reported that for oaks grown in containers for 2 years in a nursery, treeshelters reduced root dry mass, root/shoot ratio, total root length, and total root weight for valley oaks, as well as above-ground biomass for valley oak and coast live oak. However these studies were of relatively short duration and ratios might have changed if the plants were observed longer. Ponder (1996), for instance, found that tree-sheltered northern red oak *(Quercus rubr*a) seedlings harvested 3 years after outplanting in forest openings had both higher stem and root weights than seedlings not protected with treeshelters.

In this study, treeshelters promoted height growth for all species, but produced smaller stem diameters. As a result, shoot dry weight was not significantly different between protected and unprotected plants. Total root weights were similar and, as a consequence, there were no significant differences in shoot/root ratios. Treeshelters therefore did not cause a preferential distribution of photosynthate to top growth. On the other hand, it is clear that treeshelters did alter shoot morphology by creating trees that were taller, but with thinner trunks. Results indicated, however, that this characteristic diminished over time. This is very consistent with a study conducted recently at Sierra Foothill Research and Extension Center with several sizes of treeshelters (McCreary and Tecklin 2001). The key benefits of shelters, therefore, are protecting plants from damaging animals and promoting rapid initial height growth. These are important factors in a number of landscape situations, as long as the shelters are left in place long enough for the plants to develop sufficient girth to become self-supporting.

There were no significant differences for any variable among irrigation treatments. We believe that one of the main reasons we did not observe differences was the fact that this study overlapped an El Niño period in California when annual precipitation was well above normal. As a result, plants in all treatments probably had adequate natural water for near maximum growth.

Rapid growth of both valley oak and coast live oak was notable. Even though native California oaks have a reputation of growing slowly, coast live oak averaged well over 3.3 m (10 feet tall!) after 4 growing seasons, and valley oaks averaged 2.6 m, with some plants of both species nearly double these averages. Even after the first growing season, many seedlings from these two species (especially those in treeshelters) were over 2-m tall after being planted as acorns. Clearly, both of these species show great promise as landscape plants due to their good survival and rapid early growth.

Conclusions

Results indicate that valley oak and coast live oak can grow rapidly when planted from acorns in good quality soils. Protecting these species, as well as blue oak, with treeshelters promotes rapid initial height growth, but reduces stem diameter growth. As a result, shoot weights were similar after 4 years for protected and unprotected trees. There was no evidence that treeshelters caused the trees to grow more shoots at the expense of roots since we found no differences in total root weights or shoot/root ratios between protected and unprotected plants.
We also could detect no differences in variables for plants provided different irrigation regimes. Although this finding suggests that normal rainfall is adequate to establish young oak seedlings, irrigation effects may have been masked by high moisture levels during the first year.

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