AN EVALUATION OF TREESHELTER EFFECTS ON PLANT SURVIVAL AND GROWTH IN A MEDITERRANEAN CLIMATE

by Laurence R. Costello, Amy Peters[1], and Gregory A. Giusti[2]

Abstract. A four-year study was conducted to evaluate the effects of treeshelters on the growth and survival of three oak species and Douglas fir growing in a Mediterranean climate. Trees were planted in irrigated and nonirrigated plots, enclosed in treeshelters or tree guards, and measured annually for height and diameter growth. In nonirrigated plots, both treeshelters and tree guards improved oak survival, but generally did not produce significant height or diameter growth increases over unprotected controls. In irrigated plots, plant growth and survival was substantially greater than that in nonirrigated plots. Irrigated trees with protection (shelters or guards) showed substantially greater survival levels than unprotected trees. Height growth was greatest in treeshelters and diameter growth was roughly equivalent for all irrigated treatments. Irrigated trees continued to grow when irrigation was discontinued after three years, and treeshelter trees exhibited little or no lean when shelters were removed. Trees without irrigation in Mediterranean climates should not be expected to exhibit growth enhancement effects from treeshelters equivalent to those found in temperate climates.

Treeshelters are translucent, polypropylene tubes up to 2 m long which have been used to protect young trees from animal browse and accelerate height growth. By 1987, over 6 million treeshelters were reported to be in use in Britain (3), and now they are being used in many other countries (12). Originally developed for reforestation programs, treeshelters have been suggested as being useful in urban areas (5, 7) and in nursery production (14).

Growth enhancement effects of treeshelters were initially found for oak (16), and subsequently for many other hardwood and conifer species (3,6,8,9,10,14,15,17). These effects have been attributed to modifications in the plant environment: a greenhouse microclimate is created in which temperature, relative humidity, and carbon dioxide levels are increased (2,11,12,13). In addition, treeshelters protect young plants from dessicating effects of wind (1,11).

Most studies examining growth enhancement effects of treeshelters have been conducted in temperate climates, where summer rainfall is customary. In dry-summer climates, such as the Mediterranean climate of California, rainfall during the summer months is not common and soil moisture deficits can be substantial. In such areas, it was postulated that plant microclimate may not be favorably modified by treeshelters, and tree growth enhancement effects may not be realized. Indeed, Harris (5) suggested that in areas with more intense sunlight than Britain, treeshelter temperatures may rise to levels which could cause plant injury, and inferred that ventilation holes in the shelter may be needed to reduce temperatures.

This study was conducted to evaluate effects of treeshelters on survival and growth of young trees in a Mediterranean climate. For comparison purposes, tree guards (wire screens and plastic mesh) were evaluated along with treeshelters. Tree guards are commonly used to protect young seedlings but are not noted for growth enhancement effects (12). Specific objectives were: 1) to compare survival and growth of three oak species and one conifer with and without protectors (treeshelters and tree guards) in irrigated and nonirrigated conditions; 2) to evaluate the effect of ventilation holes in treeshelters on tree performance; and 3) to identify differences among test species in their response to protection and irrigation treatments. Additionally, this investigation sought to evaluate the effect of withdrawing irrigation from trees which had been established for 3 years

1. Oregon State University Extension Service, Coos County, OR.
2. University of California Cooperative Extension, Mendocino County, CA.

with irrigation, and to evaluate tree lean following treeshelter removal.

Methods and Materials

Experiments were conducted at the University of California Research and Extension Center in Hopland, California, over a four-year period. Hopland is located in an interior coastal valley in northern California where average maximum summer temperatures range from 29 to 34°C, and summer rainfall is rare. A 0.2 hectare plot of pasture land (Soquel loam) was fenced to exclude livestock and deer, and two study plots, irrigated (25 m x 11 m) and nonirrigated (25 m x 18 m), were established (Fig. 1). By using a randomized complete block design, six blocks were established in the irrigated plot and 10 in the nonirrigated plot, with plots being separated by a 6 m unplanted buffer strip. All pasture vegetation was controlled with glyphosate prior to planting.

Seedlings of blue oak (*Quercus douglasii*), valley oak (*Quercus lobata*), interior live oak (*Quercus wislizenii*), and Douglas fir (*Psuedostuga menziesii*) were planted into auger-dug holes (1.5 m centers) on March 15 and 16, 1990. Blue oak and valley oak seedlings were 6 months old and growing in leach tubes (germinated in fall, 1989), while interior live oaks were 1.5 years old (germinated in fall, 1988), and Douglas fir seedlings were 1-year-old bareroot stock. After planting, all seedlings were fertilized (60 g per plant) with Osmocote 14-14-14 (Scotts Co., Milpitas,CA), and then hand-watered biweekly with a final irrigation in June. All plants were checked for viability after 2 and 5 weeks, dead plants replaced, and replacements then hand-watered until drip irrigation began in June.

Figure 1. Tree protectors were evaluated for effects on survival and growth of three oak species and Douglas fir in irrigated (background) and nonirrigated (foreground) plots. Two tree guards, Hopland tents (plastic mesh) and wire screens, were used as well as ventilated (holes in sidewall) and nonventilated treeshelters.

Once initial establishment was complete, protection treatments (Fig. 1) were installed as follows:

Nonventilated Treeshelters (NVTS) - Tubex treeshelters (0.6 m) staked with rebar steel rods (1 cm diameter).

Ventilated Treeshelters (VTS) - Tubex treeshelters (0.6 m) with six 2.6 cm ventilation holes drilled into the sidewalls at 15, 30, and 45 cm levels. Ventilation holes were added to modify temperatures within the treeshelter. Staking was equivalent to NVTS treatments.

Hopland Tents (HT) - molded plastic mesh enclosure (45 cm high and 20 cm in diameter with 1.6 mm openings) sealed above the seedling and secured to the ground with a wire loop.

Wire Screens (WS) - window screening cut and fastened to form a cylinder around the seedling (45 cm high and 23 cm in diameter) with the top sealed and staked with a wooden stake stapled to the screen.

Controls (C) - no protection device.

The irrigated plot contained a total of 120 plants (4 species, 5 protection treatments, and 6 replications), while the nonirrigated plot contained 200 plants (4 species, 5 protection treatments, and 10 replications). All 0.6 m treeshelters were replaced with 1.2 m shelters after trees grew above the height of the shelter. Hopland tents and wire screens were opened at the top when seedlings grew to guard height.

A drip irrigation system was installed to supply water in the irrigated plot. Single emitters were placed at the base of each plant, delivering water at the rate of 3.8 liters per hour. Irrigation began in mid-May of 1990 and continued weekly through October providing 7.6 liters per week per plant. In subsequent years, irrigation began after Spring rains and until 5 cm of winter rain had occurred, with each tree continuing to receive 7.6 liters per week per plant. Drip emitters and delivery lines were checked regularly for being operational. To evaluate the effect of a cessation of irrigation in summer on growth and survival of irrigated trees, no trees were irrigated in the fourth year (1993).

Soil moisture potentials were measured using WaterMark sensors (Irrometer Corp., Riverside, CA) placed at 3 locations across both irrigated and nonirrigated plots (approximately 30 cm from trees) and at 2 depths (15 cm and 30 cm). Measurements were recorded monthly each summer. Weed control was achieved mechanically and manually in all plots. Weeds between trees were mowed, while those occurring within planting basins, treeshelters, or tree guards were hand-pulled.

Tree height (cm) and stem diameter (mm) measurements were taken after planting and then in the fall of each year (1990-1993). Diameter measurements were taken 5 cm above ground level, while height measurements were made from ground level to the apical bud or meristem of the dominant stem. In cases where codominant stems existed, competing stems were lightly headed to promote the development of a single stem. Height and diameter means for treatments were analyzed for statistically significant differences using the Tukey-Kramer HSD test for all pairs ($p = 0.05$). Tree mortality counts were made each year at the time of growth measurements.

At the end of the experiment (fall, 1993), trees in treeshelters were evaluated for lean. Treeshelters were removed and each tree assessed as either standing in an upright vertical position or leaning away from vertical. Trees leaning away from the vertical position were evaluated as having a lean less than 45° from vertical or greater than 45° from vertical.

Results

Temperatures, rainfall, and soil moisture. Summer maximum temperatures ranged from 29 to 34°C (monthly averages). When ambient temperature was measured at 36°C, average temperature in nonventilated treeshelters was 38.2°C in irrigated plots, and 40°C in nonirrigated plots. Essentially equivalent values were found for ventilated treeshelters: 37.8°C in irrigated plots and 39.8°C in nonirrigated.

Average annual rainfall for Hopland is 91 cm, with greater than 95% of this amount occurring from October through May. Rainfall during the study period ranged from 51 to 69 cm in years 1 to 3, and was 122 cm in year four. Pre-irrigation soil moisture tensions (15 cm) in irrigated plots ranged from 12 to 90 centibars (cb) during the summer months, with a mean value of 49 cb. Tensions in nonirrigated plots ranged from 83 to 199+ cb, with a mean value of 120 cb. At 30 cm, mean tension was 54 cb in irrigated plots and 141 cb in nonirrigated plots. Since moisture sensors did not record tensions higher than 199 cb, matric tensions in nonirrigated plots may have been above 200 cb for extended periods.

Survival. For all species, survival varied with irrigation and protection treatments. Overall, irrigated trees showed substantially higher survival levels than nonirrigated trees. After one year, virtually all irrigated trees survived, while nonirrigated tree survival ranged from 30 to 100% for oaks (Figs 2,3,4) and only 4% for Douglas fir (Fig. 5). After four years, oak survival ranged from 50 to 100% in irrigated plots, and Douglas fir survival ranged from 16 to 66%. In nonirrigated plots after four years, however, survival for oak species ranged from 10 to 100%, while no Douglas fir trees survived.

Protected trees had higher survival levels than unprotected trees. Survival of irrigated oaks with protectors was nearly 100% after four years, while survival of those without protectors ranged from 50 to 80%. Only 16% of irrigated Douglas fir trees without protectors survived, while 32 to 66% of those with protectors survived.

In nonirrigated plots, protection played even more of a critical role for oak survival. For all three species, survival was only 10% for unprotected trees, while those with protection ranged from 30 to 100%, with valley oak being 90 to 100%, and blue and live oak 30 to 60%.

Although all four types of protectors had a positive effect on survival, they were not sub-

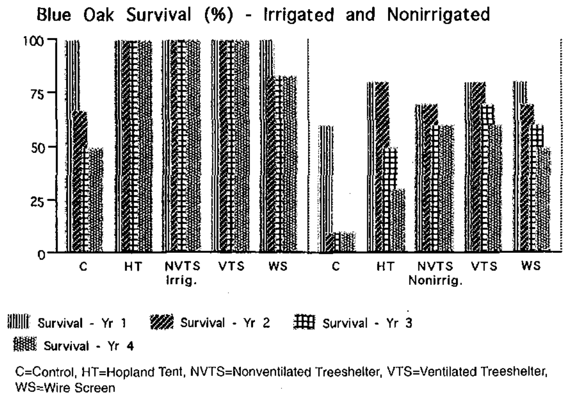

Figure 2. Irrigated blue oak survival for protected trees ranged from 83 to 100%, while only half of irrigated but unprotected trees (controls) survived. Protection also substantially improved tree survival in nonirrigated plots. C = Control, HT = Hopland Tent, NVTS = Nonventilated Treeshelter, VTS = Ventilated Treeshelter, WS=Wire Screen.

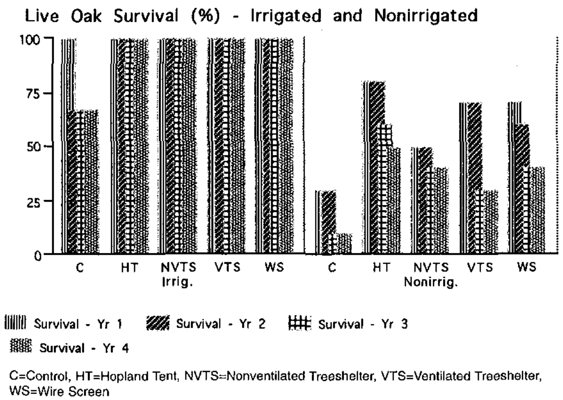

Figure 3. All irrigated live oak trees with protectors survived, while 66% of unprotected trees survived. Survival of nonirrigated trees with protectors varied from 30 to 50%, with only 10% of unprotected trees surviving.

stantially different in effect. Protectors had essentially similar effects in irrigated plots, while treeshelters gave slightly better results for nonirrigated blue oak, and Hopland tents were best for nonirrigated valley and live oak .

These results indicate that irrigation and protection together generate highest survival. Survivorship declined for trees that were irrigated but not protected, and further declined for trees that were protected but not irrigated. Survival was

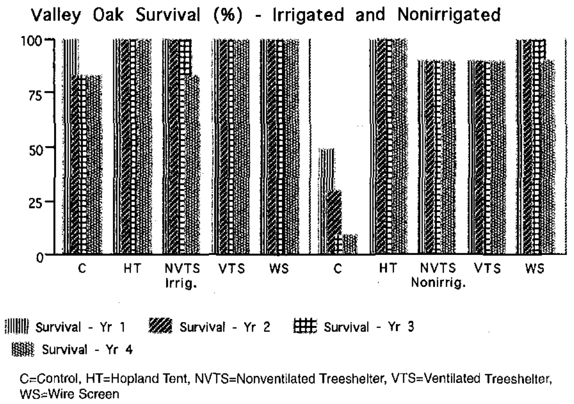

Figure 4. Irrigated valley oak survival was high for both protected and unprotected trees. Except for unprotected trees, nonirrigated tree survival also was high. In nonirrigated plots, valley oak survival was substantially greater than that for blue and live oaks.

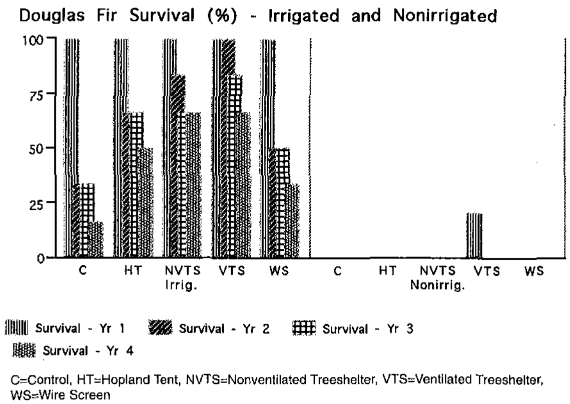

Figure 5. Survival of irrigated Douglas fir trees with protectors varied from 33 to 66%, while only 16% of unprotected trees survived. Survival in nonirrigated plots was very poor.

lowest for trees that were neither irrigated nor protected. Douglas fir did not tolerate a nonirrigated condition, with or without protection.

Height. In irrigated plots, effect of the four types of protectors on height growth varied from year to year for each species. In year one, there were no significant effects of any protection treatments on height. In years two and three, live oak trees with ventilated or nonventilated treeshelters were significantly taller than trees with wire screens, Hopland tents, or controls (Fig. 6). In year three,

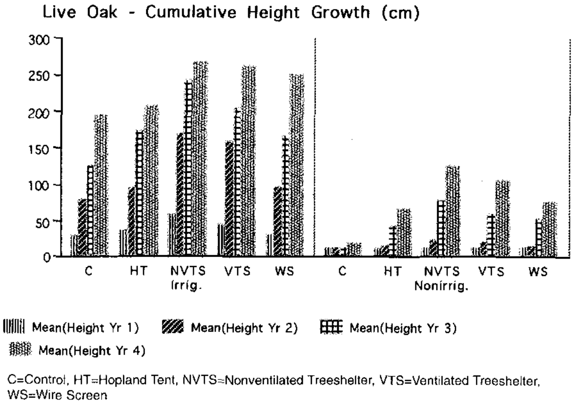

Figure 6. Height growth of irrigated live oaks was substantially greater than that of nonirrigated trees. Protected trees were taller than nonprotected trees. In years two and three, live oaks with ventilated or nonventilated treeshelters were significantly taller than trees with wire screens, Hopland tents, or controls. In year 4, nonirrigated trees with nonventilated treeshelters were significantly taller than control and Hopland tent treatments.

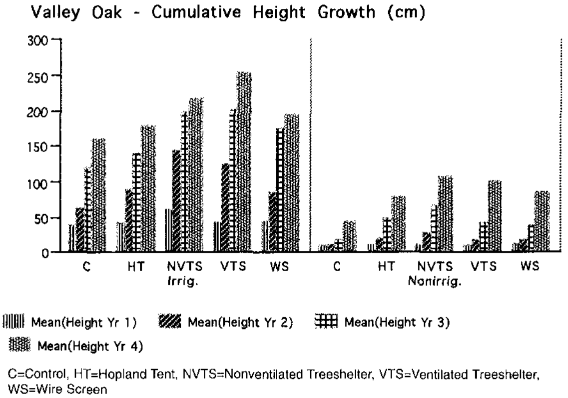

Figure 7. Irrigated valley oaks were substantially taller than nonirrigated trees. Protected trees were taller than unprotected trees in both irrigated and nonirrigated plots. In year 3, irrigated valley oaks with ventilated and nonventilated treeshelters were significantly taller than control or Hopland tent treatments, while trees with wire screens were significantly taller than controls but not different from treeshelters. In year 4, only irrigated trees with ventilated treeshelters were significantly taller than control and Hopland tent trees.

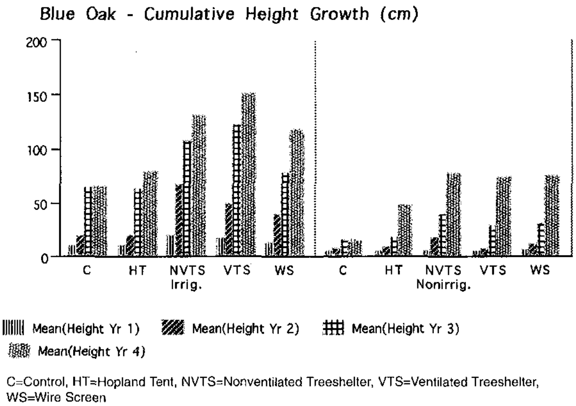

Figure 8. Irrigated blue oaks were substantially taller than nonirrigated trees. In irrigated and nonirrigated plots, trees with protectors were taller than unprotected trees. In years 3 and 4, trees with ventilated treeshelters were significantly taller than Hopland tent and control treatments.

valley oak trees with treeshelters were significantly taller than controls or Hopland tents (Fig. 7). Valley oak trees with wire screens were also significantly taller than controls, but not different from treeshelters. For blue oak in year three, ventilated treeshelter treatments were significantly taller than Hopland tent treatments (Fig. 8). In year four, valley oak and blue oak trees with ventilated treeshelters were significantly taller than Hopland tent and control treatments. No significant height effects were found for any irrigated Douglas fir protection treatments (data not shown) or any protection treatments for live oak. In nonirrigated plots only one significant difference among treatments was found during the four year study. In year four, live oak trees with nonventilated treeshelters were significantly taller than controls and Hopland tent treatments.

Generally, height growth was substantially and significantly greater in irrigated plots than in nonirrigated plots (Fig. 9). For all species after four years, irrigated trees were typically two to three times taller than nonirrigated trees.

When compared to equivalent nonirrigated treatments, significant differences in height were found for all oak species with protection in year one, and this continued through year four. Survival of nonirrigated and unprotected oaks (controls) was too low, however, to generate statistically significant differences for irrigation treatment

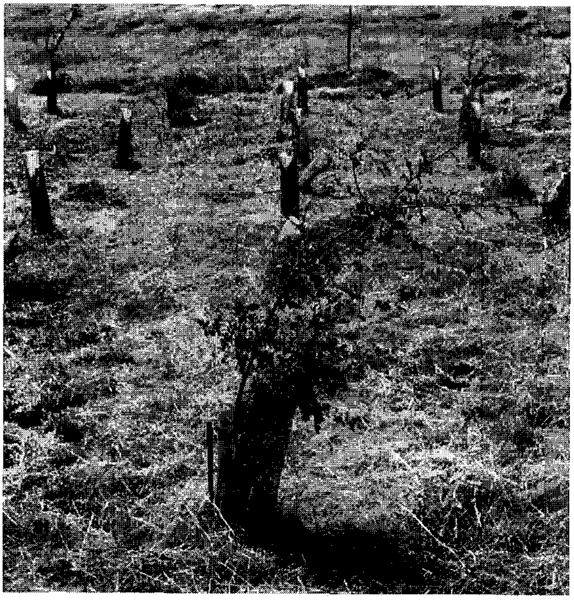

Figure 9. In nonirrigated plots, tree growth and survival was substantially less than that found in irrigated plots. Tree guards and treeshelters improved survival, but showed little difference in growth effects.

effects on height growth. This was also the case for all nonirrigated Douglas fir treatments.

Comparing height differences of oak species, irrigated valley oak and live oak with treeshelters were found to be tallest after four years, while blue oak was substantially shorter (treatments and controls) in all cases.

These results indicate that the tallest trees for all species were those that were irrigated and had a protector. Irrigated trees with treeshelters were generally tallest, followed by wire screens and Hopland tents, while trees without protectors were shortest for all species. Nonirrigated trees were substantially shorter than irrigated trees in all cases and virtually no significant differences in protection treatments on height growth were found in nonirrigated plots.

Diameter. For irrigated trees, protectors had neither a significant positive nor negative effect on stem diameter for any species or year. Although diameter differences for protector treatments were substantial for Douglas fir, these effects were quite variable and not significant. This was the only species, however, where treeshelter treatments produced stem diameters less than Hopland tents or wire screens. In nonirrigated plots, no significant differences in diameter growth were found when comparing protection treatments for oak species over the four years. Douglas fir did not survive in nonirrigated plots.

Stem diameter in irrigated plots was substantially greater than in nonirrigated plots, and these differences were significant for virtually all years, species, and treatments (Table 1). By the end of year four, diameter of irrigated trees were 2.0, 2.5, and 4.5 times larger than nonirrigated trees for blue, valley, and live oak, respectively.

These results indicate that diameter growth, as well as height and survival, was greater in irrigated plots than in nonirrigated plots. In contrast to height differences, however, no differences in diameter were produced by protectors in either irrigated or nonirrigated plots. Similar to height growth, species variation in diameter growth was evident, with irrigated blue oaks being substantially smaller than irrigated valley or live oaks. This effect was consistent but much less pronounced in nonirrigated plots. Diameter growth in Douglas fir appeared to be negatively affected by treeshelters when compared to wire screens and Hopland tents in irrigated plots.

Irrigation withdrawal. To evaluate the effect of withdrawing irrigation on tree survival and growth, water was discontinued in irrigated plots in year four. Although modest effects on growth rates were found, all trees survived and continued to grow. When compared to year three, a small decline in height growth was found for blue and valley oaks, while live oak response was variable depending on protector treatment, and Douglas fir growth rate actually increased in most cases. Similarly, diameter growth rate declined for blue and valley oak during year four, while live oak growth was roughly equivalent to that in year three. Douglas fir diameter growth continued in year four, but the rate was variable depending on the protection treatment. Thus withdrawing irrigation in year four did not substantially affect tree survival or growth. After three years, trees were sufficiently established to continue to grow without summer irrigation.

Lean evaluation. After year four, treeshelters

Table 1. Cumulative diameter growth (mm) for irrigation treatments and species. Data for protection treatments was combined since no significant differences in diameter growth were found for these treatments. Diameter growth for irrigated oaks was significantly greater than that for nonirrigated trees. Nonirrigated Douglas fir trees did not survive.

Species	Treatment	Diameter (mm) Yr 1	Yr 2	Yr 3	Yr 4
Blue oak	Irrigated	1.0	4.4	8.5	10.0
	Nonirrgated	0.1	1.4	2.5	4.8
Live oak	Irrigated	2.3	10.1	29.1	45.2
	Nonirrigated	0.7	3.1	6.4	9.8
Valley oak	Irrigated	2.9	8.8	19.8	24.3
	Nonirrigated	0.6	2.4	5.2	8.8
Douglas fir	Irrigated	1.9	7.2	14.6	21.0
	Nonirrigated	1.2	0.0	0.0	0.0

were removed and trees evaluated for lean. All live oak, valley oak, and Douglas fir trees remained in a vertical position after treeshelter removal (Fig. 10). Seven blue oak trees exhibited some lean, however, with five of these leaning 45 degrees or less from vertical. Two trees exhibited leans of greater than 45 degrees, nearly touching the ground.

These results suggest that trunk development in treeshelters can be sufficient after four years to support canopy weight. This effect may vary, however, with slower growing species (eg., blue oak) having a greater potential for lean than faster growing species (eg., valley and live oak). Even though most trees were able to remain in a vertical position after treeshelter removal, they may develop leans with additional canopy loads from wind and rain. These factors were not evaluated here, but should be carefully considered before conclusions regarding trunk strength and stability are made.

Discussion

Growth enhancement effects of treeshelters in nonirrigated plots were substantially reduced from those found in irrigated plots. While significant differences between treeshelters and tree guards were found for oaks in irrigated plots, little difference was found in nonirrigated plots. Ostensibly, lack of a treeshelter-induced growth response in nonirrigated plots is related to soil moisture deficits; as soil dries and plant water stress ensues, growth slows or ceases. Soil matrix potentials recorded in nonirrigated plots were typically 150 cb and higher during the summer months, indicating that the majority of available water had been depleted. Under such conditions, little potential for growth exists, regardless of the plant microclimate.

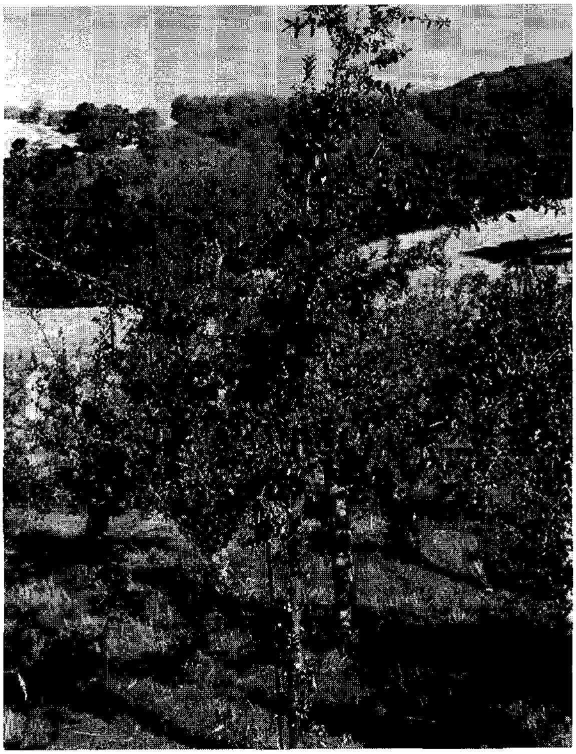

Figure 10. After four years, many oaks had grown well above treeshelters in irrigated plots. After removal of treeshelters, most trees had sufficiently well-developed trunks to maintain an upright position.

Treeshelter-enhanced height growth in irrigated oaks was consistent with findings of previous studies (12,4,16), but less pronounced in this case. Where tree height was enhanced by as much as 500% in Tuley's work with sessile oak (16), increases of only 32 to 141% were found here. Aside from differences in species' genetic potential for growth, this reduction in response may be related to differences in soil water availability at the study locations. In this study, water supplied via drip irrigation may not have maintained the same level of available water in the root zone (over time) as that at rainfall-supplied sites.

Although oak growth was favorably enhanced by treeshelters, Douglas fir growth was preferentially enhanced by tree guards. Stem diameter growth of Douglas fir was substantially greater in wire screens and Hopland tents, while height growth was greatest in wire screens. This result is inconsistent with previous reports indicating that Douglas fir growth was enhanced by 50 to 100% over tree guards (12). In this study, lateral branch growth of Douglas fir was severely restricted by treeshelters, while tree guards offered little restriction. It was only after Douglas fir trees emerged from shelters (2-3 years), that branch development occurred. This suppression of branch development in treeshelters may have contributed to the minimal response found for Douglas fir.

Both treeshelters and tree guards improved survival in irrigated and, with the exception of Douglas fir, in nonirrigated plots. However, there was no distinct difference in survival effects between the two types of protectors, suggesting that microclimate modification (characteristic of treeshelters) may not be key to improving survival. Unlike treeshelters, tree guards are not noted to modify the plant microclimate, yet they were found to improve survival to levels equivalent to treeshelters. It is possible that shading and/or protection from wind, features that both types of protectors have in common, are key to producing high survival levels, particularly in the first year after planting.

In nonirrigated plots, protectors did not improve Douglas fir survival. In fact, no Douglas fir trees survived after the first year. Certainly some difference in survival level was expected between Douglas fir and oak species in nonirrigated plots, but the extent of the difference found here is notable.

The addition of ventilation holes in treeshelters (VTS treatment) did not produce a consistent positive or negative response. Temperatures in ventilated treeshelters were essentially equivalent to those in nonventilated shelters. No distinct survival or growth advantage was found using ventilated treeshelters in either irrigated or nonirrigated plots. This result suggests that shelter ventilation to reduce temperatures in warm, dry summer climates is not necessary.

While differences in survival and growth response to protectors have been noted between Douglas fir and oaks, differences among oak species were also notable. Aside from inherent differences in growth rates of each species, the most striking difference found was in valley oak survival levels in nonirrigated plots. Virtually all valley oaks with protectors survived, while live oak and blue oak survival was substantially less. It is possible that early and deep root development of valley oak may have resulted in an ability to extract water from deeper in the soil profile than blue or live oak. This result invites further investigation into valley oak tolerance of arid conditions.

Neither withdrawing irrigation in the fourth year nor lean of trees protected by treeshelters were found to be problematic. Growth of irrigated trees continued after irrigation had been withdrawn. This suggests that root development of irrigated trees was sufficient after three years to sustain top growth without supplemental irrigation. Trunk development of trees in treeshelters was also sufficient after four years to support canopy weight. Although trunk taper was not equivalent to trees without protectors, diameter growth was adequate to maintain a vertical stature in most cases. Blue oaks were somewhat less developed than live and valley oaks in this regard, however, and treeshelter removal may need to be delayed for blue oaks until an increase in trunk caliper is achieved. In addition, trees were not evaluated for lean under additional canopy load, such as from wind or rain, and further assessment of their ability to withstand such loads is recommended before decisions are made regarding treeshelter removal.

Considering the three protectors from a practical perspective, treeshelters appear to offer the most advantages. Not only do they provide growth and survival benefits equivalent to or greater than tree guards, they help to facilitate weed control, their height makes plants easier to locate, and, unlike tree guards, they do not need to be opened when plants reach the height of the protector. In addition, treeshelters were found to be easier to install and more durable than wire screens or Hopland tents.

Conclusion

Although treeshelters were found to enhance growth of oaks in irrigated plots, they did not generate equivalent effects in nonirrigated plots. In summer-dry climates, treeshelters without irrigation should not be expected to enhance plant growth as they have been found to do in temperate climates. Irrigation alone had a more substantial effect than treeshelters in survival and growth of both oaks and Douglas fir. When irrigation is not available, protectors will improve survival for oaks, but not for Douglas fir. Overall, irrigation and treeshelters together provided best results for tree survival and growth in a Mediterranean climate.

Acknowledgment. The authors gratefully acknowledge the assistance and support of the staff of the Hopland Research and Extension Center. A grant from the Renewable Resources Extension Act provided funding for this research. Manuscript review and comments by Dr. David W. Burger (University of California, Davis) were greatly appreciated.

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University of California Cooperative Extension
625 Miramontes, Rm 200
Half Moon Bay, CA, 94019

Zusammenfassung. Es wurde eine Studie geleitet, um die Auswirkungen von Baumschutzhülsen auf das Wachstum und das Überleben von drei Eichenarten und einer Douglasie in mediterranem Klima zu bewerten. Die Bäume wurden in bewässerte und unbewässerte Pflanzlöcher gesetzt, sie wurden umgeben von Baumschutzhülsen oder Fegeschutzbändern und ihr Höhen- und Dickenzuwachs järhrlich gemessen. In den nicht bewässerten Pflanzungen verbesserten die Baumschutzmaßnahmen das Überleben der Eichen aber sie produzierten keinen nennenswerten Zuwachs an Höhe oder Umfang gegenüber ungeschützten Pflanzungen. In bewässerten Pflanzungen war das Wachtum und die Überlebesrate deutlich größer als bei unbewässerten Pflanzungen. Die bewässerten Bäume mit Baumschutz zeigten deutlich größere Überlebensraten als ungeschützte Bäume.