Irrigation and Rangeland Oaks

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The problem of oak tree regeneration and recruitment has been the focus of much research in California in recent years. The University of California and the U.S. Forest Service have sponsored four comprehensive symposia devoted to the subject of oaks and hardwoods, and many scientists and concerned citizens have sought answers and remediation. Concern has led individuals to form the California Oak Foundation, dedicated to the preservation and regeneration of oaks and their habitats.

That some species of native California oaks are not reproducing well was observed nearly 90 years ago (Sudworth, 1908; Jepson, 1910). More recently Griffin (1971, 1973) called attention to the lack of regeneration in blue oaks and valley oaks. Replacement rates are especially low in the coastal ranges and foothill regions of the state (White, 1966; Steinhart, 1978). When a blue oak sapling is found, it is likely to be in a relatively moist habitat (Bolsinger, 1988). Callizo (1983) suggests that newly emerged valley oak seedlings will not survive their first year without one or two summer rainstorms, and because these happen so seldom in a century, one sees even aged stands and few young trees. McCreary (1990) discusses the "pulse" theory of several necessary contemporaneous factors for regeneration to take place.

Bartolome et al. (1987) state that the more successful regeneration is occurring at upper elevations. When a rainfall map is consulted, it is clear that these are areas of greater precipitation, especially in the spring and summer. Soil moisture depletion caused by a five to eight month dry period can cause deaths of seedlings (Pancheco, 1987; Larson and Whitmore, 1970; Lathrop and Osborne, 1990).

Acorns germinating on north facing sites or in shade are more likely to survive than those in the open (Barbour, 1987). Thus, we view desiccation as a major potential cause of early mortality. There are some published reports on the effects of supplemental irrigation on oak seedling survival and growth.

McCreary (1990a) found more frequent watering was beneficial at least during the first year, but he used small volumes. Bernhardt and Swiecki (1991) reported only 4 percent of valley oak seedlings planted under irrigation died, while 43 percent of non-irrigated seedlings died their first year. Meyer (1991) found that well watered seedlings grew taller and had more leaves than seedlings without supplemental water. Costello, Schmidt and Giusti (1991) working at a site 40 kilometers south of our study site found the growth of irrigated oak seedlings to be about five times that of those left to nature.

Another experiment by Costello et al. (1996) at the same location with blue oak, interior live oak, valley oak and Douglas fir reported much better growth and survival rates for irrigated seedlings.

Summary of Species Characteristics Used in this Experiment

This study used four species of oaks common to the Northern California Coast Ranges: blue oak (*Quercus douglasii* H. & A.), California black oak (*Q. kelloggii* Newb.), Oregon white oak (*Q. garryana* Dougl.) and interior live oak (*Q. wislizeni* A. DC.). Each of the four species selected for this study grows well in the study area, although seedlings of all but interior live oak are uncommon to rare. Blue oak generally lives in drier, hotter areas of lower elevations and while it can survive with only 35 cm of annual precipitation, it does better in areas where rainfall is about 65 cm. California black oak is found at higher elevations than blue oak and does better with 90 cm of rain than 65 cm. The live oaks do well on hillsides, but better on north-facing slopes or in canyons and near stream beds where water is available later into the summer. Oregon white oak requires more moisture than the others and this study site is near the southern limit of its distribution.

Questions and Hypotheses

The normal summer dry period in the study area lasts five to eight months, and there is added moisture stress due to the competition from grasses. In this study we wanted to find out what happens to the survival and growth of oaks under differing watering conditions throughout several summers. We were also interested in determining if there is an optimum amount of irrigation to apply for each species, an amount below which survival is in serious jeopardy, and an amount above which growth is retarded. We hypothesized for all but the Oregon white oak that there would be some range of water providing maximum growth over a summer, and with more or less applied water, there would be a decrease in relative growth.

We hypothesized that the Oregon white oak would grow best with a high amount of water.

Methods and materials

Site

The study area is located in Redwood Valley, 18.9 km north of the city of Ukiah in Mendocino County, CA at an elevation of 270 meters. The site is covered with grasses and forbs and has not been grazed for over 10 years. This site was chosen because it receives full sunlight and becomes very dry during the summer. This land has a 9 percent slope with a northwest aspect, and the soil type is Pinole loam.

Experimental Design

Acorns were collected from healthy trees all within 0.6 km of the study site and were picked in October, 1991. On 13 December the acorns were planted in 38 cm long planting tubes. Many of the blue oak and some of the Oregon white oak acorns were already sprouting. All acorns were positioned on their side, and any visible radicles were pointed down.

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A rectangular grid was laid out at the site (Fig. 1) and water collecting cans were placed in four rows of seven cans each. The distance between cans in a row and between rows was 4 m. Three overhead irrigation sprinkler heads were placed so that some cans received no water at all and some cans a great deal of water (Table 1). The sprinkler placements were arranged to provide a smooth continuum from no water to maximum water. With an array of 28 irrigation measuring cans, we chose 42 seedlings of each of the four species and assigned six seedlings to each can. The seedlings were planted in a hexagonal arrangement 1 m to aside and 1 m from the measuring can. The assignment of trees to cans was random to the extent that each can received at least one tree and no more than three trees of each species.

The test plot was fenced to prevent deer and rabbits from entering the exclosure. We provided no other assistance to the oak trees. In order to maintain reasonably natural field conditions, we did not scrape or mulch the soil around the trees but did mow the area twice each summer to provide access.

Measurement of Soil Moisture

We buried gypsum based soil moisture sensors and temperature probes at depths of 30 cm, 90 cm and 150 cm in different locations, corresponding to sites receiving varying amounts of irrigation. After calibrating the sensors to this soil, measurements were made with an electrical resistance soil moisture meter. Readings corrected for temperature were taken every four days beginning in March.

Experimental Procedure

We planted the seedlings on 13 March 1992. We used a bimonthly measuring schedule beginning 15 March. Height was taken to the tip of the main leader. Seedlings were eventually placed into one of three categories. The first was that of continuously living seedlings which had retained the original growing leader and growth results are presented only for this group. This group was analyzed for growth using descriptive statistics and one way analyses of variance on the log transformed data. The second group consisted of trees which survived but lost their main stems; analysis is restricted to survivorship because they could provide no growth information. The third group consisted of trees that died.

Results

Annual Growth Patterns in Trees with Original Leaders

1) Phase 1—Irrigation with Overhead Sprinklers

The seedlings of each species of oak demonstrated a characteristic optimal range of water needs each summer. For both blue oak and California black oak the medium amount of water from irrigation and rainfall (approximately 42-63 cm each summer) resulted in significantly better growth than either lower amounts (23-41 cm) or higher amounts (>64 cm).

The heights over time of the California black oak are shown in Fig. 2, a nearly identical pattern was shown by the blue oak, and a similar one by the interior live oak. The growth dif-

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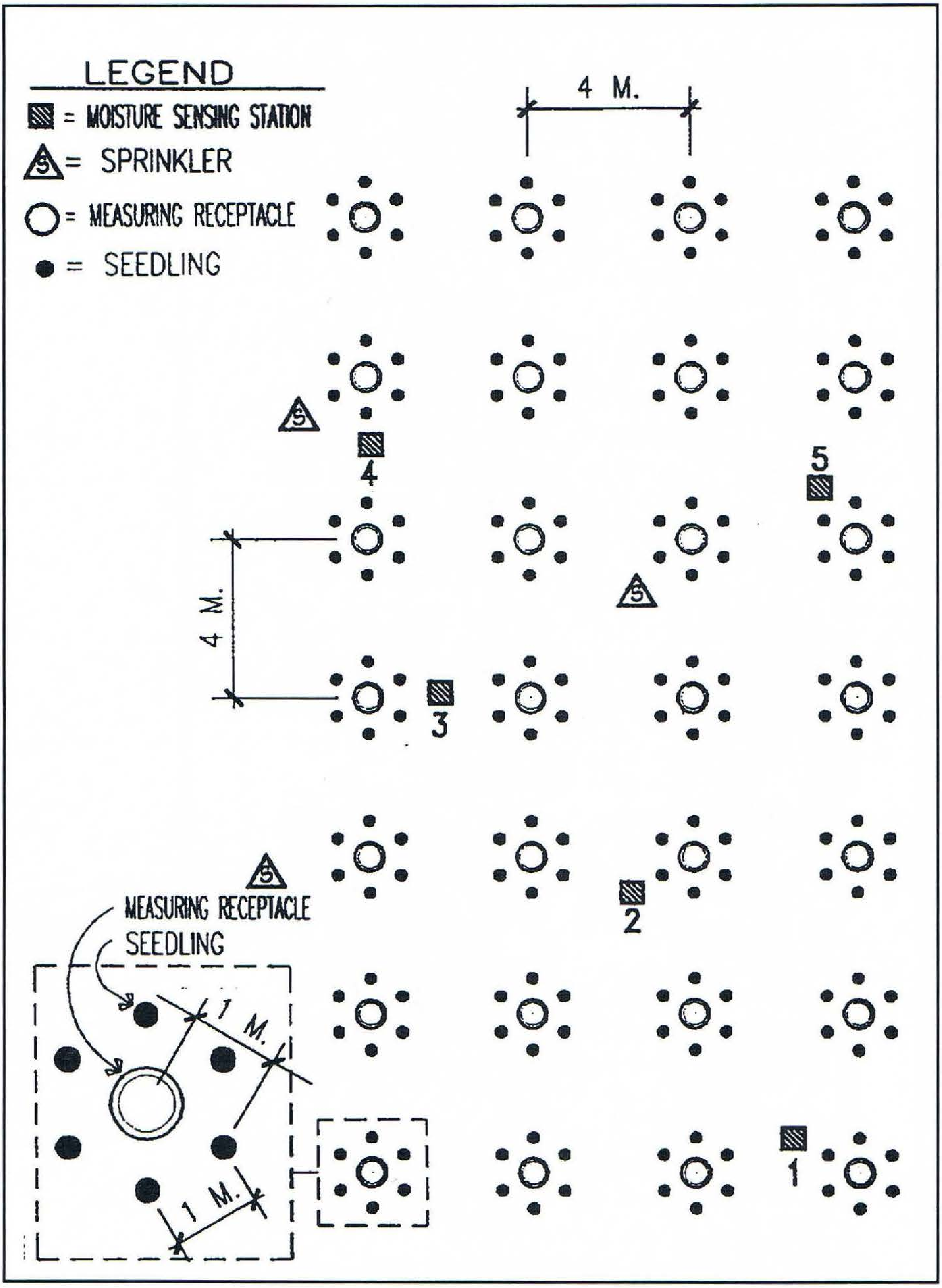

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Figure 1. Experimental layout showing arrangement of collecting cans, 168 oak seedlings, soil moisture stations and sprinklers.

Table 1. Amounts of water received by 4 species of oak seedlings during 4 years (15 March through 15 November). Mean values followed by ranges in parentheses, and measurements in cm. The 15 March - 15 November rainfall was 23.1 cm in 1992, 33.5 cm in 1993, 24.6 cm in 1994, and 42.2 cm in 1995. Subtract these from tabulated figures to determine irrigation water.

Year	Low	Medium	High
1992	30.5 (23-41)	44.7 (42-51)	64.8 (52-75)
1993	42.6 (34-50)	57.3 (51-63)	70.5 (64-79)
1994	34.8 (25-46)	54.0 (47-61)	72.3 (62-85)
1995	50.2 (42-62)	66.3 (63-71)	78.1 (72-88)

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ferences showed up statistically in the third year for blue oak ($p<.01$) and in the fourth year for California black oak ($p<.05$). The blue oak trees receiving the low irrigation scheduling grew from an average height of 17 cm to an average height of 31 cm in four years, while those in the medium irrigation scheduling went from 15 cm to 68 cm. Those receiving high amounts of water grew from 12 cm to 43 cm. For the interior live oak, both medium amounts of water (42-63 cm) and high amounts of water promoted significantly greater average growth than the low water (23-41 cm) scheduling ($p<.01$). This difference showed up in the third year. There was no significant growth difference between the medium and high water conditions. Growth after four years in the low water scheduling was from 22 cm to 88 cm, in the medium water condition from 27 cm to 216 cm, and in the high water condition, from 24 cm to 188 cm. While the survival rate of interior live oak was significantly less than the other three species, those which did survive grew very fast under optimal conditions.

The pattern for the Oregon white oak differed from the others in that the trees with the most water each year grew somewhat taller than those with either medium or low irrigation, and although differences showed a clear trend (Fig. 3), they were not statistically significant.

2) Phase 2— With Drip Irrigation

In 1996, we switched irrigation scheduling, so the blue oak, California black oak and interior live oak trees which had been getting a medium amount of water now received a low amount, and vice versa. The trees going from medium to low were well enough established so the reduced irrigation slowed the growth rate only moderately. But there was a dramatic increase in growth when going from low to medium irrigation. For the interior live oak, the change was little short of miraculous. In four years of growth under low irrigation, the average height was 88 cm; the next year, with more water they grew an additional 63 cm, and through September 1997 achieved a mean height of 178 cm. The Oregon white showed a dramatic increase when changed from a low water to a high water regimen. In the first four years of low water, average height increased from 10 cm to 36 cm; in the last two years with enough water, they more than doubled their height to 77 cm, and are now nearly as tall as the trees which had first received high water and were changed to the low water sched uling.

Mortality

As anticipated, some trees died during the experiment. Twenty-three of the 168 healthy seedlings planted succumbed during the first four years, and one more died in the fifth year. While the distribution of dead trees was uneven with respect to species, time and amount of water received, the cause of death in all cases appeared to have been desiccation. None was lost to mammals, birds or insects.

With respect to time, 16 trees died in 1992, five in 1993, two in 1994 and one in 1996. Mortality was clearly seasonal, with 17 deaths in the hot period. Mortality was also dependent on irrigation scheduling, for 16 of the 23 trees that died were in the group receiving the least water during phase 1. This was highly

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significant (chi-square = 13.6; p<.005). This finding underscores the importance of maintaining sufficient water throughout much of the summer.

Discussion

By the end of Phase 1 of the experiment, the growth of all four species was least under the lowest irrigation scheduling, and best under medium irrigation for three of them. For blue oak and interior live oak height differences were highly significant (p<.01) by the third year. For California black oak statistical significance was obtained in the fourth year. The Oregon white oak seedlings showed a clear trend for maximum height under a high water regime. Phase 2 changed irrigation from low to medium, or in the case of Oregon white oak from low to high, which resulted in a dramatic increase in seedling heights, and demonstrated the importance of abundant supplemental irrigation. Where there was low supplemental water, soil moisture from the surface to a depth of 30 cm was rapidly depleted by early summer. At 90 cm deep, the depletion rate was slow until mid July when the depletion rate rapidly accelerated and the soil became very dry by early September. At a depth of 150 cm deep, the soil stayed nearly at field capacity until mid July, then gradually dried for the rest of the

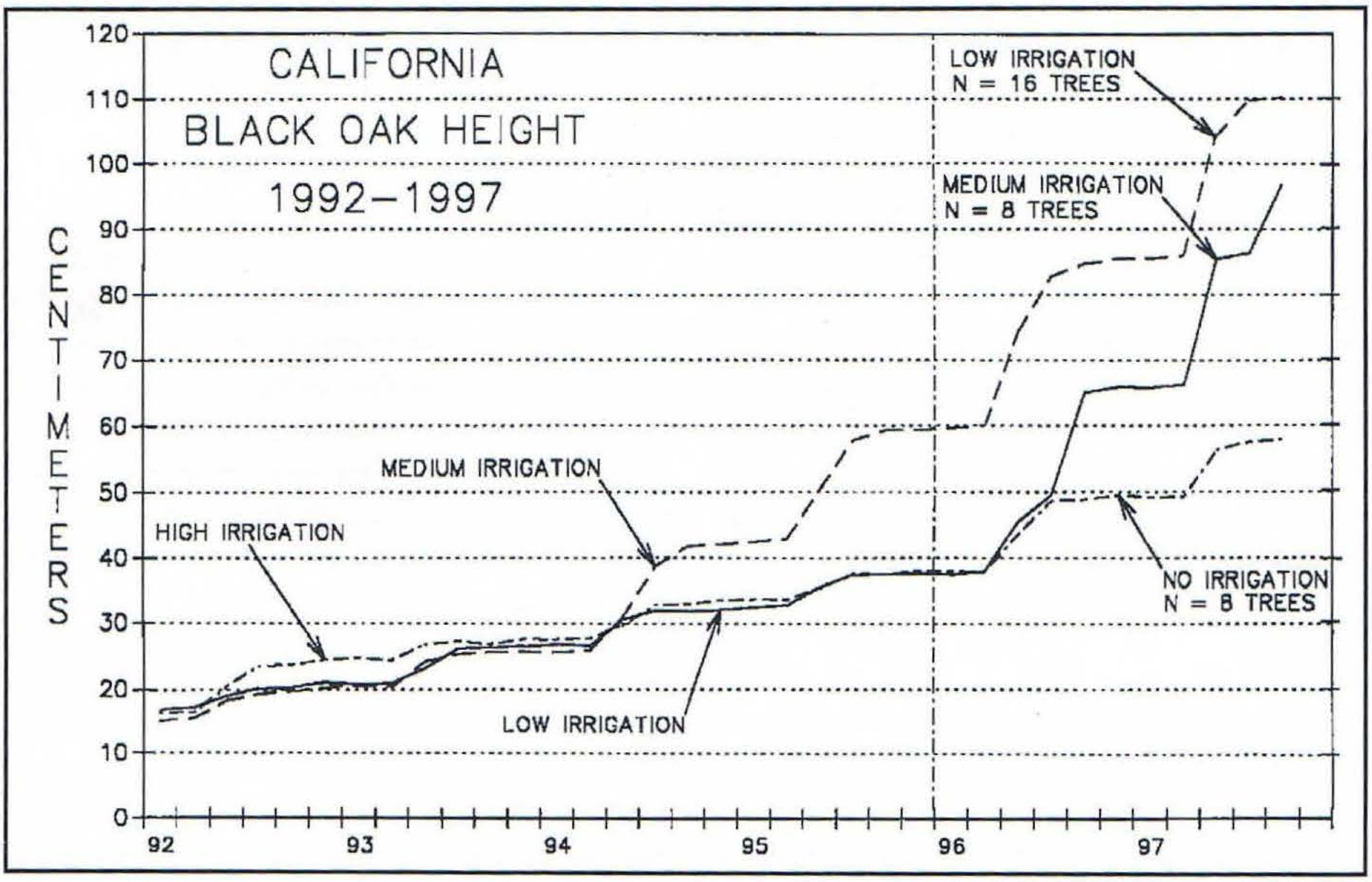

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Fig. 2. Mean heights of 32 California black oak seedlings 1992-1997. Note changes in irrigation scheduling in 1996.

summer.

First year seedlings are at great risk with little or no irrigation. In fact, five of the six seedlings near the driest moisture site died and after four years the single living specimen (a blue oak) has grown only 10 cm. When this blue oak received adequate water by drip during the next two years, it grew an additional 12 cm.

For the medium irrigation, soil moisture values at the 30 cm depth went very low during the summer, but this happened late enough not to cause damage. At the 90 cm depth, the soil contained water until September or later. At the 150 cm depth, the added water at the medium irrigation sites served to keep the soil not far below field capacity. The wettest areas received from 52-88 cm of water, and about half was after July. The soil never dried out at 90 cm deep or at 150 cm deep, never aerated properly, and kept roots very wet. Even at 30 cm deep, there was no drying cycle, only a cycle from field capacity to moderately wet and back to field capacity. There was no mortality at this level of irrigation but seedlings did not grow well, the Oregon white oak excepted.

The shorter heights of seedlings in the high water conditions has alternate explanations than just too much water. Very heavy application of water supports a lush grass cover, and the grass may in part be responsible for the slowed growth due to competition for nutrients or production of allelopathic chemicals. Excess water probably causes oxygen deprivation in the soil, and as Costello, MacDonald and Jacobs (1991) demonstrated, blue oak is highly sensitive to an hypoxic condition. Water stress in some plants results in better root exploration of the soil and more root proliferation (Hsiao and Acevedo, 1974).

Under natural conditions better regeneration has been found with trees in moister conditions such as the higher mountains, north exposures, and where the water table is reasonably shallow, such as river bottomland soils. Extra water is imperative for good growth; supplemental irrigation extends the growing season, mimics late spring and early summer rains and counteracts the desiccating effects of introduced annual grasses. Typically, this area of the north coast receives 11 cm of precipitation from mid-March to the end of July, so irrigation is important. In our experiment eight of the ten trees which died by 15 July of the first year had received less than 21 cm of combined rain and irrigation. This strongly suggests they need at least 25 cm of water by that date, or seedling survival is in jeopardy. If more than 60 cm of water is applied from March through November growth suffers, although the effects of the surplus water are not fully known; perhaps there is no harm to young trees. We do not advocate watering trees all summer into fall. We do advocate extending the spring and summer wet period at least through July.

Under natural conditions, seedling growth extends from March through June and part of July, with very little growth afterward. Further growth adds leaves but little height. With supplemental water, the growing season is extended significantly, and there is still modest growth into September.

We have shown that the growth differences under varying irrigation schedules appear in the second year, and by the third and fourth years, may be quite dramatic. There is no doubt that the added water is the extra factor. In subsequent years, less water may be preferable. In the fifth and sixth years, we altered the irrigation schedule. Only one tree died, but the changed schedule showed different growth patterns (Figs. 2 and 3). The trees which first received low water and then were shifted to a medium amount began to thrive and show a growth curve similar to those which initially received a medium amount of water. Those which had initially received a medium amount and then were given a low amount slowed their growth rate. The condition of global warming has come to be widely accepted. If the amount

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of available soil water has indeed decreased over time due to climate change or groundwater pumping, then the supplemental water given to seedlings effectively restores the more "normal" conditions of the past. The acorns and seedlings may require more water than is naturally available now. Use of supplemental irrigation of seedlings may in many areas be necessary for successful regeneration, in spite of considerable added cost.

Conclusions

The results from this study demonstrate that for oak seedlings to thrive, they need appreciably more water than is generally available by rainfall alone, and more than is applied in most oak regeneration experiments. Survival is highly dependent on adequate water during the first year.

Growth, on the other hand, is far more dependent on adequate water during the warm season for at least several years. To ensure survival of planted oak seedlings, one must provide about 40-50 cm of water from March through November, and to obtain good growth, it is necessary to apply about 25-30 cm from March through the end of July, through rain or irrigation.

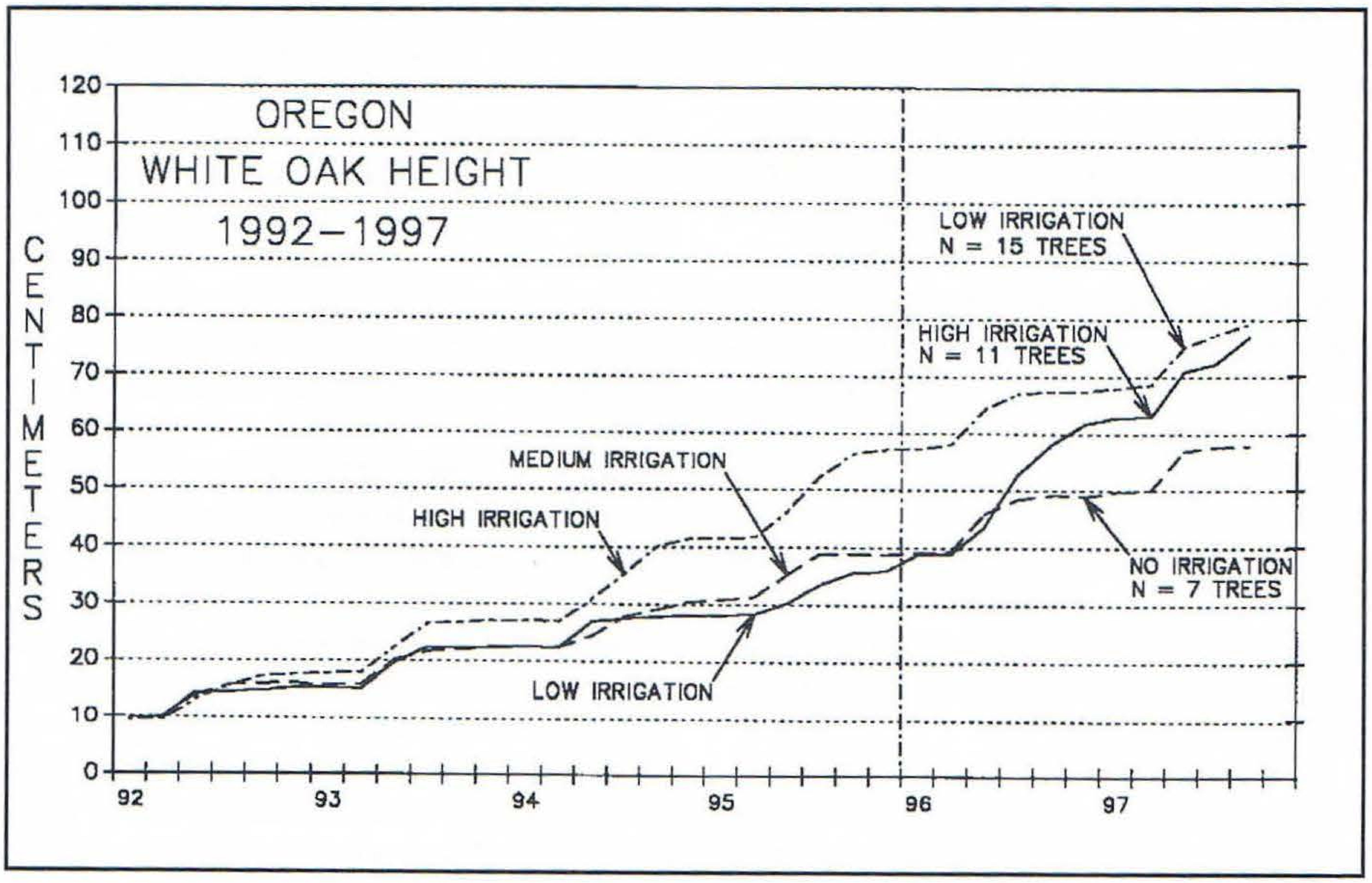

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Fig. 3. Mean heights of 33 Oregon white oak seedlings 1992-1997. Note changes in irrigation scheduling in 1996.

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