SELECTED TECHNIQUES FOR RESTOCKING HARDWOOD RANGELANDS IN CALIFORNIA WITH NATIVE OAKS

A Report Submitted to the

THE CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE PROTECTION

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EXECUTIVE SUMMARY

In California today, there is concern that native oaks are not being managed properly. One issue that has been repeatedly identified is poor natural regeneration of several oak species. An in-depth assessment of this problem was recently funded by the California Department of Forestry and Fire Protection, Forest and Rangeland Resource Assessment Program (FRRAP). While this report (Lang, 1988) concluded that widespread statewide regeneration failures had not been scientifically documented because of a lack of clear information about stand structure and mortality over time, it did find that there are critical sites where natural regeneration is likely to be inadequate. In addition to these critical sites, there also are locations in the state where extensive clearing has occurred and all oak trees have been removed. Obviously, there is little chance that these areas will naturally revert to woodland communities in the near future.

Since the overall goal of the Integrated Hardwood Rangeland Management Program is "to maintain and where possible increase the acreage of California's hardwood range resources", techniques are needed to supplement natural regeneration in areas where it is inadequate, and to restore native oaks in some areas where they have been previously removed. To accomplish this it will be necessary to develope successful artificial regeneration procedures. To date, however, there has been relatively little research in this area. While seedling production and planting techniques for oaks have been developed, they have been primarily for landscape use and have not been evaluated or tested on hardwood rangelands.

The following research proposal was designed to evaluate a variety of approaches for successfully regenerating native oaks in an oak woodland setting. The ultimate goal of this project is to provide information for use in developing effective regeneration procedures that will allow rangeland landowners and managers whose management objectives include maintenance or enhancement of oak woodland habitat, practical low-cost methods for restocking native oak species.

The project described herein was a team approach with five investigators working in different regions of the state. It consisted of six separate studies, each focusing on a different aspect of regeneration. Each of the three white oak species (blue, valley and Englemann) reported to be regenerating poorly were investigated in one or more of the studies. The overall objectives of each of the six studies are listed below.

Study 1. To determine if larger acorns produce greater initial root growth, allowing seedlings to tap deeper reserves of soil moisture, and as a result, survive and grow better during the initial establishment period.

Study 2. To determine if sowing acorns deeper, and placing multiple acorns per hole, results in reduced animal predation and greater seedling emergence and growth.

Study 3. To determine if root pinching, mycorrhizal inoculation, irrigation, or auger planting improve the ability of Englemann oak seedlings to survive and grow in the field.

Study 4. To evaluate the effects of placing time release fertilizers in planting holes and determine if these treatments improve the ability of oak seedlings to survive and grow in a non-irrigated environment.

Study 5. To evaluate the effects of alternative lifting and storage treatments on the nursery production of bareroot oak seedlings, and develop guidelines to assist nursery operators to produce healthy, vigorous stock for outplanting.

Study 6. To compare the field performance of direct seeded acorns to 2-3 month old container stock and determine if seedings can be successfully established without protection from grasshoppers and small mammals.

All studies, except Study 2, were evaluated for two full field seasons. This allowed a more accurate assessment of survival, since it was difficult, if not impossible, to determine if seedlings were really alive after the initial planting season since many lost their leaves and appeared dead before the end of the first summer. The second-year growth data also provided an opportunity to determine if trends observed in the first year persisted over time. In general they did, and second-year data reinforced the conclusions outlined in preliminary drafts of this report.

This report is divided into two main sections. The first part summarizes the literature on oak propagation and planting methods. The second part describes the research studies that were conducted. In this section, each study is reported separately. Although writing styles of the different investigators differ, we tried to maintain a consistent format by providing methods, results, discussion, and conclusions sections for each study.

Brief summaries of the main findings of each study are provided below.

Study Summaries

Study 1. Acorn size influenced blue oak seedling performance, with higher survival and greater initial growth for larger acorns. The most dramatic effect of increased acorn size was the ability to produce a larger, more developed root system. However, the actual field gains for larger acorns were relatively small during the first two years and varied greatly according to the parent tree from which the acorns were collected.

Study 2. Acorn planting depth dramatically affected the degree of depredation for both blue and valley oak, with greater depredation for shallower plantings. However, emergence of non-depredated acorns was inversely related to planting depth. Planting acorns 2-inches deep was deemed best for both species because it was deep enough to reduce depredation, but shallow enough to permit emergence. Planting several acorns per planting site reduced depredation and increased seedling emergence, survival, and growth.

Study 3. Of the treatments evaluated, the most effective method of increasing the growth of Englemann oak seedlings was to amend planting sites with soil collected from beneath mature trees. Radicle pruning, on the other hand, had a negative effect, causing pregerminated acorns to die before emergence. Neither irrigation nor augering greatly affected seedling survival or growth.

Study 4. Planting date had a greater influence on blue and valley oak seedling survival than fertilization, with early planting resulting in the most rapid and complete emergence. Of the fertilizer treatments evaluated, fast release (3-4 month) osmocote placed 8-inches below the soil surface consistently depressed emergence, suggesting that high nutrient concentrations may have damaged developing seedlings. Fertilizer placement depth also affected seedling responses. Shallow (8-inches) placement of slow release agriform tablets resulted in consistently better growth than deeper placement (24-inches), or a combination of deep and shallow placement.

Study 5. One-year old blue oak seedlings produced in a bareroot nursery had high survival and vigorous growth as long as they were lifted and planted early enough in the planting season to become established before soil moisture became limiting. Seedlings could be successfully lifted over a fairly broad interval, extending from early December until early March. If they were lifted by January, they could also be stored for up to two months with little or no degradation in quality. However, late lifting combined with long storage, resulted in reduced survival and growth.

Study 6. Protecting outplanted seedlings with aluminum screens had a small but positive effect on improving the growth and survival of blue and valley oak seedlings. However, there was little difference between directly sowing acorns and planting small seedlings. Overall planting success in response to protection and stock type varied considerably among planting location.

Recommended Techniques

Based on the findings in these six studies, we developed a list of recommended planting and protection techniques. These recommendations are divided into three general categories:

1) Acorn collection, treatment and planting
2) Seedling propagation
3) Seedling maintenance and protection

It should be noted that these recommendations are based upon studies that were, in general, only replicated at one site and only evaluated one or two oak species. Since site conditions can vary greatly and responses can be different for different species, care should be exercised in extrapolating these recommendations to other sites and species. For instance, while Study 4 found little benefit from fertilization, in a separate study at the Sierra Foothill Field Station not funded by this project, significant positive responses to fertilization have been found. In spite of these limitations, it is hoped that these recommendations will provide some valuable guidelines for restocking oaks on hardwood rangelands in California.

Acorn collection, treatment and planting

COLLECTION:	Where possible, select the largest acorns for outplanting (however, planting of smaller acorns may also be necessary to ensure adequate genetic diversity and use of local seed sources)
TREATMENT:	For pre-germinated acorns, leave the radicles intact and do not prune
PLANTING:	Plant acorns early in the winter. Prior to planting, amend planting sites with soil collected from beneath mature trees. Where acorn predators are present, plant acorns 2 inches deep. Plant several acorns per planting spot.

Seeding propagation

BAREROOT PRODUCTION: Lift one-year old seedlings between early December and early March. Store seedlings in cold storage for up to 2 months. However, avoid the combination of late lifting and long storage, and plant seedlings by the first of March.

ACORNS VS CONTAINERS: When there is a choice between directly planting acorns or growing seedlings for 2-3 months in containers and then outplanting, choose the former. These perform as well in the field and are far cheaper to procure and plant.

Seedling maintenance and protection

IRRIGATION: In soils with adequate moisture holding capacity, irrigation is generally not necessary for survival, as long as there is adequate weed control. However, irrigate to increase growth (if this can be done in a cost-effective way).

AUGERING: Auger sites prior to planting to a depth of 3-feet to enhance early seedling growth. This practice has little effect on survival and is recommended only where site conditions permit easy application.

FERTILIZATION: Do not fertilize with granular osmocote at the rate of 4 grams of elemental N per seedling, since this tends to suppress survival and growth. Slow release agriform tables also provide little net benefit beyond the second year. However, if tablets are used, place them approximately 8 inches below the soil surface.

PROTECTION: Cover outplanted seedlings or acorn planting spots with aluminum screen cages or other protective devices to minimize insect and small mammal herbivory.

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In addition to the lead investigators, others also contributed to the preparation, writing, and review of the various sections of this report, including Jerry Tecklin, Sherryl Nives, Nanette Pratini, Lillian Hall, and Rick Standiford.

Finally, we would like to thank the Butte Fire Center for help in collecting acorns in Study 1; the California Conservation Corps in San Luis Obispo for building the deer fence for Study 2; the Superintendents and staffs of the Hopland, South Coast, and Sierra Foothill Range Field Stations for plot maintenance in Studies 1, 3, 4, 5, and 6; the CDFFP Magalia Nursery and its manager Bill Krelle for producing the seedlings for Study 5; and the California Conservation Corps' Napa Nursery and its manager Chris Sauer for producing the seedlings used in Study 6.

LITERATURE REVIEW

I. INTRODUCTION

The first task outlined in the RFP for this project was to "review and evaluate previous and ongoing studies on oak propagation and planting methods." We included a preliminary literature review in the initial project proposal. Preparation of this review revealed that there were a multitude of references on this subject, spanning an extremely wide temporal and geographic range.

Our strategy for preparing a more comprehensive review was to identify first pertinent references through a series of catalogue and computer-assisted library searches; and second, to evaluate and review this information and prepare a summary report. As the search for references began, it soon became clear that we would have to limit the subject area covered since there are literally thousands of references under the broad title of "oak regeneration" We therefore decided to focus on four specific subject areas listed below:

1. Acorn collection, storage and handling
2. Seedling propagation
3. Site preparation and planting
4. Acorn and seedling protection

We collected references on each of these topics (over 400 in all) and assigned one of the co-investigators on this project to review materials and prepare a chapter summarizing the literature for one of the four subject areas.

This division of responsibility worked well except that our geographical separation made it difficult to regularly compare notes. We also discovered that these subject areas were not always discrete and separate. As a result, when we put the chapters together, we found that there was occasional overlap. For instance, some of the concerns regarding maintaining seed quality were addressed in both the section on acorns and the one on planting. We decided not to eliminate these duplications since we also wanted each of the chapters to stand on their own. We were afraid that if we started chopping material out, we would reduce the effectiveness of the chapters in thoroughly addressing the respective subject areas. It should also be noted that throughout this review both metric and english terms are used. Since there was no consistent use of terminology in the articles reviewed, we could either convert everything to one consistent format, or we could report results as they appeared in individual articles. We chose the latter.

Finally, as we prepared this review we realized that there is still a great amount of information on these subject areas that we did not cover. Numerous studies on oaks have been completed in Europe and the Soviet Union, but unfortunately, most of these are not in English. There are also a number of reports from several decades ago that are in rather obscure publications that are difficult to find. And lastly, since this is an area of great current interest new studies are being conducted continually and research findings updated. Even the research projects funded in this grant have added substantially to the knowledge in California species, yet these are not included in this literature review. Therefore, we do not claim to have covered the subject area completely. However, we do feel that the following review addresses the important findings and provides a detailed and useful overview of the state of knowledge on this important subject.

II. ACORN COLLECTION, STORAGE AND HANDLING

A. INTRODUCTION

Seed production in *Quercus* is notoriously unpredictable. A comprehensive review of factors in continental climates affecting acorn production, germination, and early seedling growth identified the extreme variability of acorn production (Olson and Boyce, 1971). This variability exists within and between species and among locations and years. When production is poor, few acorns capable of germination survive predation. In California statewide crop failures are not uncommon (Hannon *et. al.*, 1987). Timing of collection, sorting methods, and manipulation of storage conditions can be used to increase germination percentages, uniformity of germination times, and the overall success of a planting project.

Acorns are recalcitrant, which means that unlike many other seeds, they cannot be stored under below-freezing, low-humidity conditions without loss of viability. These requirements pose several challenges for those attempting to store acorns, as moist, above freezing temperatures also favor diseases and early germination. Furthermore, optimum storage conditions vary among species, particularly between the two major subgenera of *Quercus*.

Relatively little research has been done on the requirements of California species, whereas practices concerning economically important Southeastern species are fairly well established. The literature in this area is dominated by the work of F.T. Bonner and J.A. Vozzo, both of the Southern Forest Experiment Station in Starkville, Mississippi.

B. ACORN ANATOMY AND PHYSIOLOGY

The three basic parts of a mature acorn are the shell, or pericarp, the seed coat, or testa, and the paired cotyledons containing the rudimentary root and foliar structures. The cotyledons are very large in comparison to most tree seeds and contain enough minerals and food reserves to supply the developing seedling until it can develop photosynthetic tissue.

Throughout acorn maturation, dormancy (or storage) and germination, many changes in acorn structure, metabolism and chemical composition occur. Understanding these changes can help us provide optimum conditions for acorn survival or allow us to manipulate them to suit our needs.

1. Maturation

In general, acorns of the White oak[1] subgenus (*Lepidobalanus*) mature the same year as fertilization, but in acorns of the Black oak subgenus (*Erythrobalanus*), maturation is delayed until the following year. During early maturation (roughly June to August), acorns increase in length, diameter and weight, reaching maximum size usually sometime in September (Bonner, 1974; Bonner and Vozzo, 1987). Moisture contents increase along with fresh weight and then decrease rapidly from late August to early October, reaching about 40% of fresh weight for Black oak species and 50 to 55% for White oak acorns (Bonner, 1974; Bonner, 1976b). Corresponding to this loss of moisture is a change in pericarp color from bright green to dark brown (Black oaks) or yellow to brown (White oaks), due to a gradual loss of chlorophyll (Blanche, *et. al.*, 1980).

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[1]to avoid confusion subgenera names will be capitalized (e.g. White oak), while species names will remain lowercase (e.g. White oak).

Carbohydrates, the major food source in White oak acorns, account for 40-50% of dry weight at maturity in White oak acorns and 25-30% in Black oak acorns (Bonner, 1974; Bonner, 1976b). During early maturation, the soluble carbohydrate fraction gradually increases until around September when the insoluble carbohydrate fraction rises as the soluble sugars are converted to insoluble forms (Bonner, 1974; Bonner, 1976b).

Lipids, the major energy source in Black oak acorns, increase during late maturation and reach a peak at maturity of 10 to 30% dry weight in Black oak and 3 to 11% dry weight in White oak acorns (Bonner and Vozzo, 1987; Ofcarcik and Burns, 1971; Tucker, 1974;

Wainio and Forbes, 1941). Nitrogen (both protein and soluble fractions), phosphorus, calcium and magnesium levels all gradually decline towards maturation in willow (*Q. phellos*), water (*Q. nigra*), cherrybark (*Q. falcata* va. *pagodaefolia*), white (*Q. alba*) and Shumard (*Q. shumardii*) acorns (Bonner, 1974; Bonner, 1976b). The protein reserves in acorns are relatively low in comparison to other seeds, ranging between 3 and 8% of dry weight (Bonner and Vozzo, 1987; King and McKlure, 1944; Ofcarcik and Burns, 1941; Wainio and Forbes, 1941). Soluble tannins decrease towards maturity and are generally higher in Black oak acorns than in White oak acorns (Koenig and Mumme, 1987; Ofcarcik and Burns, 1971; Wainio and Forbes, 1941; N. Pratini, unpub. data). Within the seed, protein, carbohydrate and phospholipid reserves gradually concentrate in the embryo axis, particularly in White oak acorns (Vozzo, 1978; Bonner and Vozzo, 1987; Vozzo and Young, 1975).

2. Dormancy

Acorns of the White oak subgenus may exhibit epicotyl dormancy until spring (Clatterbuck and Bonner, 1985), but radicle emergence during storage is often a problem. Black oak species of colder climates go into a dormant state at maturation, which can be prolonged during storage, and then may require a chilling period (stratification) to break dormancy before germination can occur. Most low-elevation California oaks will germinate readily soon after collection (Schettler and Smith, 1979).

In a study of three Black oak and one White oak acorn species stored at 2 °C for 6 to 8 months (Clatterbuck and Bonner, 1985), soluble carbohydrate and moisture levels gradually increased during storage while crude fat levels decreased, as lipids were apparently metabolized to more usable energy forms. Insoluble carbohydrates gradually increased at first and then decreased during radicle elongation as they too were apparently metabolized. Respiratory quotients increased significantly during the entire period, corresponding to the metabolism of first lipids and then starches. Trends were similar for all species, but the White oaks relied to a greater extent on their larger carbohydrate reserves for metabolism than lipids.

In nursery practice, stratification is used to break dormancy. The conditions for stratification are similar to those for long-term storage (high moisture level, cold temperature), but more closely mimic early spring conditions. During stratification, metabolic activity within the cotyledons increases and nutrients are transported to the developing embryo in preparation for germination.

The factors controlling dormancy are not completely understood, although growth regulators are thought to play a significant role. In one study, indoleacetic acid (IAA) in stratified water oak acorns gradually decreased while levels of abscisic acid (ABA) and gibberellic acid (GA) increased (Hopper and Vozzo, 1982). The pericarp is also thought to have an important role in dormancy regulation (Korstian, 1927; Peterson, 1983; Bonner, 1968; Hopper, 1982). It may act as a mechanical barrier to cell expansion or gas exchange, or may release growth inhibitors.

3. Germination

During germination, starches, lipids, and proteins are translocated from the cotyledons to the embryo axis, primarily to the developing root (Bonner and Vozzo, 1987; Vozzo and Young, 1975). The radicle emerges first and elongates to form a tap root. The plumule, containing the shoot, emerges later and the cotyledons remain attached below ground to nourish the developing plant until the end of the first growing season.

C. COLLECTION AND SORTING

Choices made regarding the time of collection, the trees to collect from, and which acorns to save for storage or immediate sowing can significantly affect the success of a planting project.

1. Timing of collection

Generally speaking, the closer acorns are to maturation, the more likely they are to produce a healthy seedling. In most species of the Southeast, immature acorns do not germinate well. Germination percentages of willow and cherrybark acorns went from less than 60% in acorns collected on Oct. 6 to 95% and 74%, respectively, in those collected Nov. 1 (Bonner, 1974). Water oak acorns in the same study showed no seasonal trend in germination success, but Blanche *et. al.* (1980) observed an increase from near 0% to nearly 100% germination between July 30 and Sept. 30, but no appreciable change between Sept. 30 and Oct. 30 in the same species. In a separate study, white oak acorns averaged 0% germination on Sept. 21, 50-57% germination on Oct. 18, and 75-83% germination by Nov. 1., while Shumard acorns did not achieve above 40% germination unless collected after Oct. 18 (Bonner, 1976).

However, collecting prior to maturation may be more convenient and may increase the chances for successful storage due to the greater moisture content of the acorns. In many California species, acorns can be collected well before full maturity and still be viable. Acorns of blue oak (*Q. douglasii*) collected August 27 and Sept. 9 germinated faster and more completely than acorns collected in late October (McCreary, 1990a). Plumb (1982) collected viable acorns as early as late July in black oak (*Q. kelloggii*), early August in canyon live oak (*Q. chrysolepis*) and interior live oak (*Q. wislizenii*), and late August in scrub oak (*Q. dumosa*). Early-collected acorns did not germinate well unless the tips of the pericarps were removed however, and those of the first three species required stratification before germination. Collection after the first drop is also recommended (Schettler and Smith 1980; Bonner and Vozzo, 1987), as the first acorns to fall are usually aborted or infested.

2. Indices of maturity

Both water content and carbohydrate percent are closely correlated with maturity but are impractical to measure in the field. Change in shell color, from green to brown or black, depending on species, is also a reliable indicator and much more convenient. Other physical characteristics of maturity include easy removal from the cup or a bright cup scar, or cotyledons that are dark yellow to orange in high-fat species or white to yellow in low-fat species (Bonner and Vozzo, 1987).

3. Methods of collection

Picking mature acorns off oak trees will result in the highest percentage of sound acorns (Teclaw and Isebrands, 1986), but collecting from the ground is much cheaper and easier. When collecting from the ground, acorns can either be raked or a dropcloth can be spread under the canopy. Although acorns often appear to mature at different rates depending on location in the canopy, collection from four strata within the canopy had little effect on germination success in one study (Teclaw and Isebrands, 1986).

Care should be taken to prevent drying of the acorns after collection. Blue oak acorns losing to only 10% of their initial fresh weight can suffer a significant decrease in germination rate, and those losing 25% can suffer a complete loss of viability (McCreary, 1990a). Korstian (1927) noted than white oak acorns could withstand more drying than red oak (*Q. borealis*) acorns (cotyledons down to 30-50% and 20-30% initial fresh weight, respectively) without an appreciable loss of viability. He postulated that the higher lipid content of red oak acorns resulted in less free water available to the embryo.

4. Influence of source trees

Acorn crops of individual trees within a species, even close neighbors, can vary considerably in time of maturation, size of crop, acorn size, and acorn quality. Genetic influences can often outweigh environmental conditions or acorn size as a determinator of germination success and seedling growth (Gysel, 1956; Aissa, 1983; Hunter and VanDoren, 1982; Farmer, 1974; Allen and Farmer, 1977). Artificial selection to maintain or increase desirable traits of source trees combined with plantation-style silviculture of oaks as practiced in Europe may have potential in the U.S. for large-scale operations such as lumbering. For other purposes, such as small-scale reforestation or reclamation projects, the loss of genetic diversity associated with plantation-style harvesting should probably be avoided. Although our knowledge of population genetics in *Quercus* is minimal, it would seem prudent to use seed sources from within the area to be planted. Source trees that are known to be reliable producers of high quality acorns can be nurtured in the wild by a program of supplemental watering, fertilization, or insect control (Schettler and Smith 1980; Detwiler, 1943).

5. Sorting and cleaning

The flotation test (Bonner and Vozzo, 1987) is a fairly reliable sorting technique and can also be used to hydrate acorns prior to storage and to remove unwanted materials. When placed in water, sound acorns will generally sink and unsound acorns, along with leaves, acorns cups and other unwanted items will float. The "sinkers" usually germinate faster and more completely than the "floaters", especially for ground-collected acorns, but a significant fraction of tree-collected floaters may also be sound (Teclaw and Isebrands, 1986). If the acorns are dry, some may sink after several hours of soaking, so in these situations it is best to leave the acorns in water for 16-20 hours (Bonner and Vozzo, 1987). Soaking healthy acorns will not always improve germination rates and storage success (McCreary, 1990a), but desiccated acorns can regain their viability if rehydrated quickly (Agmata and Bonner, 1985). A visual inspection of the "sinkers" after flotation to discard damaged or weeviled acorns will further increase overall viability (Abrahamson, 1978).

Sizing acorns is another way to improve overall acorn quality, although it may only be practical in cases were only large seedlings are desired or uniformity of samples is a concern. Acorn size has been found to be positively correlated with several measures of seedling development in several species (Korstian, 1927; McComb, 1934; Farmer, 1980). Rink and Coggeshall (1983) suggested that survival on dry sites could be related to acorn size since large acorns have greater germination, better survival, and produce larger seedlings than small acorns. If true, seedlings that develop where it is dry and depend on a maximum of stored nutrients from large cotyledons may be exposed to a selection process favoring large acorns.

6. Tests for viability

In some cases it may be desirable to test a representative sample of acorns from a lot prior to storage. Several standard tests used by the seed and nursery industry (AOSA 1984) have been applied to acorns with varying degrees of success.

In a standard germination test, acorns are cut in half, the end with the cup scar is discarded and the pericarp is then removed from the apical end. The peeled halves are germinated on a moist medium and germination counts at selected intervals are recorded. Expressions of germination rate are generally better predictors of vigor than overall germination percentages, but do not always correlate with seedling performance (Bonner, 1974; Bonner, 1984; Bonner and Vozzo, 1987).

More rapid viability tests have been devised to overcome the 3-4 week waiting period needed in germination tests. These include examining a cross-section of acorn for color and damage, radiography to look at embryo development, immersion in water and then measuring electrical conductivity or solute concentrations of the leacheate, and staining the cotyledons with tetrazolium chloride (TZ) (Bonner, 1984; Bonner and Vozzo, 1987). Of these, the staining test has proved to be the most reliable. Correlations between TZ tests and germination tests or seedling vigor have been variable, however (Bonner, 1974; Bonner, 1984; Bonner and Vozzo, 1987). Part of this variability can be attributed to species differences. Cotyledons of water oak acorns fit together too tightly to allow adequate penetration of the stain. Penetration is also inhibited in those species with a rough or thick seed coat such as willow, water, and Nuttall (*Q. nuttallii*) oaks. In white oak or other species likely to have the radicle protruding through the pericarp, the cotyledons often split apart when the acorn is cut open cross-wise. Cherrybark, Shumard, and scarlet oaks (*Q. coccinea*), on the other hand, are well suited to TZ testing (Bonner, 1984).

D. STORAGE

The key issues in acorn storage are: (1) moisture loss, (2) rates of germination and radicle emergence, (3) pathogenic fungi, and (4) gas exchange. The life histories of most acorn pest species, such as weevils (*Curculio* spp.), preclude invasion of acorns that have been collected and stored (Bonner and Vozzo, 1987). (Although insect larvae in acorns at the time of collection will continue to damage cotyledons, as discussed above in III.E.). All techniques of storage stressed the delicate balance in creating conditions that would maintain moisture but would neither promote fungal growth nor restrict gas exchange.

White oaks can only be stored for relatively short periods (4 to 6 months) of time; Black oaks acorns can be stored for up to 3 years, but acorn viability decreases with time in storage (Bonner and Vozzo, 1987). The best conditions for storage depend on the species of acorn and on the objective of the seed handler. Fall sowing is usually recommended for White oak acorns, and White oak acorn storage could be considered a form of enforced dormancy. Black oak acorns generally store well for several months or more. In eastern Black oaks, storage is used be to shorten the period of dormancy and promote early or more uniform germination dates. Handling acorns in such a manner as to overcome dormancy is termed stratification, although the conditions for regular storage are often sufficient to break dormancy without any further treatment.

1. Pretreatments

Authors have suggested treating acorns primarily to control premature sprouting and overcome dormancy. Few authors suggest treating acorns with fungicides because of the danger to seedling tissues and because beneficial fungal associations, such as ectomycorrhizae, could be damaged. Treatment with growth regulators has been suggested as a method of controlling premature sprouting during storage (Bonner, 1970), but is not widely practiced. Ancak (1973) reported some degree of success in prolonging storage of Slovene English oak (*Q. robur* var. *syrmatica*) when the acorns were treated with low concentrations of isopropyl-N-phenylcarbamate. However, Bonner and Vozzo (1987) have tested a variety of growth inhibitors with little success.

Removal or cracking the acorn pericarp, treatment with gibberrelic acid (GA3), a growth regulator, or a combination of the two treatments prior to stratification have been used to overcome dormancy in some species. Since most California species are not subject to harsh winters, this type of acorn treatment is uncommon in the state. Plumb (1982) suggested removal of scrub oak acorn pericarps if acorns were collected before they reached maturity. Authors have used pericarp removal with mixed success in eastern oak species. Allen and Farmer (1977) found no benefit from pericarp removal in bear oak (*Q. ilicifolia*), but R. Johnson (1979) increased the germination percentages in Nuttall oak acorns and Farmer (1974) was able to shorten the stratification period and increase the germination percentage in red oak acorns.

2. Storage Conditions

Bonner and Vozzo (1987) suggest that optimal storage conditions: (1) maintain high moisture levels within acorns (45 to 55% in white oaks, >30% in black oaks), (2) keep acorn temperature slightly (2 to 5°C) above freezing, and (3) allow for gas exchange. These conditions parallel the natural environment where acorns overwinter and germinate.

Of the numerous techniques tested by researchers, acorns stored alone in polyurethane bags in cold storage appear to give the most consistent results (Bonner, 1970; Rink and Williams, 1984; Bonner and Vozzo, 1987). Polyurethane bags with wall thicknesses of 4 to 10 mils are ideal for black oak acorns, allowing respiration without excessive loss of water (Bonner, 1970; Bonner and Vozzo, 1987). White oak acorns, which are non-dormant, require thin polyurethane bags (1.75 mil) or cloth bags (Rink and Williams, 1984; R. Johnson, 1979). Packing materials for storage include: sand, peat (R. Johnson, 1979; Ancak, 1973), and sawdust (Suszka and Tylkowski, 1982). These materials may reduce the passage of pathogens between acorns, but the extent of this benefit has not been clearly shown (Bonner and Vozzo, 1987).

3. Pathogens in Storage

Bonner and Vozzo (1987) note that pathogen damage to acorns is most likely to happen during storage; however, few researchers have sought to develop techniques for reducing fungal and pathogenic infections. The temperature of storage seems to be the primary means of reducing fungal infections. The high water content of acorns renders them susceptible to the toxic effects of fumigants such as methyl bromide, carbon disulfide, or thiamine bisulfate. These agents can also damage any inoculant of beneficial fungi that may be on acorns. The consensus of authors appears to be no treatment other than cleaning and cold temperatures for the prevention of fungal damage.

E. STRATIFICATION AND GERMINATION

Most studies of acorn germination have taken place in areas with cold winters where acorns must overwinter in woodland soils. Many authors discuss the need for cold temperatures for stratification, a condition not needed by most California oak species. Manipulations such as pericarp removal or cold temperature storage do appear to increase the percentage of germinating acorns (Plumb, 1982). Acorn storage prior to planting is used by California nursery personnel to insure the sowing of germinated acorns, but this storage has questionable value in stratification (Schettler and Smith, 1980). The cost of planting acorns which fail to germinate has undoubtedly promoted the industry to use storage as a method of insuring growth from planted acorns. The disadvantages of germination prior to planting is that acorns with emerging radicles slow handling time, can be damaged, and can clog sowing machines (Bonner and Vozzo, 1987). Several authors (Bonner, 1982; Bonner and Vozzo, 1987) have shown that damaged radicles do not prevent seedling emergence and that seedling production is not necessarily affected by radicle trimming.

Most researchers in the eastern United States work with acorns that are planted prior to germination. Little research has been conducted on handling of acorns between germination in storage and planting in restoration sites.

III. SEEDLING PROPAGATION

A. INTRODUCTION

Most of the native oak seedlings currently produced in California are grown in containers. These vary in size from "liners" -- small 2-inch diameter, plastic boxes -- to larger 15 gallon pots. Often seedlings are started in liners, and then transplanted to larger containers after six months or a year. It's hard to determine exactly how many seedlings are produced annually, but a 1987 survey of nurseries specializing in native stock indicated it was probably less than 200,000 (McCreary, unpublished). A sizeable proportion of these were coast live oak (*Quercus agrifolia)* since these are widely used as a landscape plant. Because there is little demand, relatively few native white oaks are currently grown.

While few oak seedlings are produced in California, large numbers are grown in other parts of the county as both bareroot and container stock. Production techniques for both of these stock types have been developed and evaluated and there is a wealth of information on specific culturing practices. However, even in other parts of the country native oaks are still considered difficult to artificially regenerate, so there is an on-going effort to improve seedling propagation techniques so that "better" seedlings can be produced, resulting in improved outplanting success.

B. BAREROOT NURSERY CULTURING METHODS

1. Sowing

The Hardwood Nurseryman's Guide (Williams and Hanks, 1976) recommends that oaks be sown either in the fall or spring at a depth of between 1/4 and 1-inch. Methods of sowing include hand broadcast seeding, hand drill marks, mechanical drill and mechanical broadcast. For most oaks, mechanical sowing equipment has not been developed so the most common method is to hand sow in drill marks.

Seed sown in the fall should be mulched over winter. A variety of materials including straw, sawdust, pine needles, or cloth can be used. Mulches prevent erosion and frost heaving and may be left in place to delay early spring germination and help prevent damage from spring frosts. For spring sowing it is necessary to artificially stratify those species that require stratification (members of the Black oak group).

The orientation of acorns during sowing can influence seedling development, with improper positioning resulting in distorted growth. Some preliminary experiments with several oaks reported that when directly seeded in pots, embryo on side position is best, and embryo up position worst (Appleton and Whitecomb, 1983). When the seed is pre-germinated and the orientation of the seed is changed at planting time, stem or root distortions were frequently evident.

2. Seedbed Density

Seedbed density is another important consideration for nursery propagation and directly affects the number of plantable seedlings produced in a given amount of bed space. It can also greatly influence the physiological and morphological characteristics of seedlings, as well as total production costs. Barham (1980) compared seed densities of four, six, eight, and ten seedlings per square foot for cherrybark oak and found that the number of plantable seedlings increased with seedbed densities, but seedling heights and root collar diameters were not affected. The cull percent, however, was significantly lower at the lowest density, indicating that the number of plantables per pound of seed was highest for the lowest density. Wichman and Coggeshall (1983) compared densities of four, eight and twelve seedlings per square foot for 1-0 white oak and found that lower seedbed densities resulted in significantly higher seedling calipers. Height was unaffected. They concluded that seedbed density of eight seedlings per square foot resulted in the lowest total cost, although the cost for the three densities did not differ greatly. Hodges and Elam (1984) also found that for several southern oak species a bed density of eight seedlings per square foot yielded more plantable seedlings than lower densities, and as many seedlings as higher densities. In a study with 2-0 white oak, on the other hand, Wichman and Coggeshall (1984) found a density of four seedlings to be best since there were unacceptably high cull percentages at higher densities.

3. Root Pruning

In nursery beds, oaks typically produce a deep prominent tap root unless their root systems are somehow modified. Undercutting roots using a sharp blade drawn through the soil can help restrict such deep root development and can increase the production of lateral roots. According to Toliver *et al.* (1980).

> Root pruning seedlings in the nursery during the growing season prior to lifting should increase the number of root tips and allow development of more compact, fibrous root systems. These root systems should be less prone to damage during lifting, thus the seedlings may not undergo as much shock when transplanted and survival should be better.

Several studies have investigated the effects of nursery root pruning. In a recent series of experiments, P. Johnson (1989) found that root pruning northern red oak increased lateral root dry weight at the time of planting; dry weight and surface of tap roots, fine lateral roots, and course lateral roots; and survival and probability of long term establishment success. However, Toliver *et al.* (1980) found no effect of lateral root pruning on the height or survival for two species of oak four years after outplanting.

Several other studies have examined the effects of pruning roots after seedlings have been lifted. Larson (1975) found that root pruning northern red oak *(Quercus rubra* L.) greatly affected subsequent seedling growth with marked reductions in shoot growth, as the severity of root pruning increased. Moderate root pruning, however, had little negative effect. Trees root pruned to 15.0 and 7.5 cm had good root regeneration, while those pruned to 2.5 cm produced few new roots. Beckjord and Cech (1980) also found that severe root pruning after lifting resulted in the greatest mortality. However height growth differed little among their treatments and they concluded that good survival of field planted oaks was possible as long as two-thirds of the tap roots were left in tact. Russell (1973) reported that root pruning at the time of planting to either 5- or 8-inches (from an original length of 11-inches) had no effect on 6-year survival or height.

4. Top Pruning

Top pruning can also affect the physiology and field performance of oak seedlings. This culturing technique has been suggested as a means of decreasing the initial shoot-root ratio, thus improving the chances for successful establishment. Top pruning can also be used to create seedlings of uniform size and to facilitate the handling of otherwise large, bulky plants. Adams (1984) reported that pruning water oak seedlings to either 2.5 cm or to one-half of their initial height resulted in a vigorous, fast growing sprout. While total height of unpruned seedlings was more after two seasons in the field, the new growth for pruned seedlings was much greater. He concluded that "vigor associated with pruned seedlings may increase survival and result in more stems per acre". However, the timing of top pruning can be critical to field performance. Larson (1975) found that any top pruning treatment that removed leaves in the late summer or early fall markedly reduced root regeneration and initial shoot growth after planting in March. Top pruning in January, however, resulted in exceptionally good root regeneration. It also tended to increase the number of new stems per tree and resulted in earlier bud break in the spring. Larson concluded that oak seedlings should not be top pruned in the seedbed during the fall, but that moderate top pruning in the spring can be used to facilitate handling. P. Johnson (1979), on the other hand, found that shoot clipping had a consistently negative effect on root growth for both bareroot and container stock.

Russell (1973) evaluated the effects of top pruning at the time of planting and found that top-pruned seedlings had greater initial growth which compensated for height loss incurred by the pruning treatments. Toliver *et al.* (1980) found that top pruning had little effect on survival or height growth for water and willow oaks and that both species completely recovered from the top pruning within the first season after planting.

5. Lifting Date

Williams (1963) found that there were no differences in field survival or height growth between fall and spring lifted northern red oak seedlings. In some situations, fall lifting may be preferred since it allows nursery operators to keep equipment off of wet nursery beds and ensures that stock is available for shipping on short notice. J. Adams (1986) compared six lifting dates between January 22 and March 5 and found that water oak seedlings lifted on the later dates leafed out later than seedlings lifted on earlier dates. He felt that poor performance was related to the longer photoperiods later in the season which contributed to more dieback and transplant shock. He concluded that seedlings lifted late in the growing season have "significantly less chance of surviving and competing with wild seedlings and other vegetation".

6. Cold Storage

There has been relatively little research about the storage environment for lifted oak seedlings. Burns (1986) reported that several oak species cold stored for three months survived well after outplanting. Webb and von Althen (1980) compared several storage regimes and packing medium for a variety of hardwood species including northern red oak. They found that storage at -5 °C and -10 °C resulted in low root growth capacity and was generally detrimental. They recommended that the seedlings be stored at 0.5 °C with a relative humidity of 70 to 85 percent, and that roots be surrounded by moist peat. The seedlings should also be tightly enclosed within a kraft bag with a polyethylene liner. It is also imperative that seedlings be hardened off before being lifted for storage (Peevy, 1976).

C. CONTAINER SEEDLING PRODUCTION

Oak seedlings have been successfully grown in greenhouses and shadehouses using a variety of container types, potting mixes and environmental conditions. According to Tinus (1978):

> The strategy for raising container seedlings is to get prompt and complete seedling germination, rapid height growth until the seedling is as tall as desired, and then apply the final stage of hardening to set and develop the buds and add caliper and lignification.

1. Container Size

The size of the container used can influence the size of the plant produced as well as outplanting performance. Elam *et al.* (1982) compared three container sizes for growing four species of southern red oak and found that seedlings grown in 0.9ℓ containers performed best based upon space, handling, planting ease, and quality of the seedlings. Hathaway and Whitcomb (1977) however, found no difference in tree growth for Shumard oak seedlings grown in containers ranging from 676 to 1360 cubic centimeters (41 to 83 cubic inches). For hardwoods in general, Tinus (1978) recommends a minimum container size of 10 cubic inches and preferably 25 cubic inches.

2. Growing Media

The growing media can also greatly affect seedling growth. Hannah and Lowe (1978) compared nine different media and found that potting mixes that contained peat moss and vermiculite were superior to those that did not contain vermiculite. With vermiculite the water holding capacity, the cation exchange capacity, and the effective rooting volume of each container was increased. Tinus (1980) recommended a growing medium of 1:1 horticultural grade number 1 or number 2 sphagnum peat moss and vermiculite with 3 to 5 millimeter particle size, which is well drained and has good water-holding capacity. Hathaway and Whitcomb (1977) also found that nutritional status is critical for subsequent performance. Seedlings propagated with the highest fertility had increased survival and faster growth following transplanting.

3. Environmental Conditions

Tinus (1980) has extensively studied the greenhouse production of bur oak *(Quercus macrorarpa)* seedlings and has developed a schedule for producing two crops of seedlings per year. He recommends growing seedlings between 21 °C and 27 °C until the first leaves have expanded. Watering should be as needed to keep the rootball moist, but the surface allowed to dry between waterings. After the seedlings are well established, the day temperature should be increased to 32°C and enhanced CO_2 provided. Fertilizers should be added to the irrigation water. Hardening of seedlings is necessary before they are outplanted and can be accomplished by placing seedlings outside or reducing temperatures in the greenhouse.

Supplemental lighting may be used to extend photoperiod and stimulate growth. Maxfield (1975) successfully sped up the growth of *Quercus ilex* with an extended day-length. He found that the larger the plants were in the beginning, the more they grew with the lights on them. However, Tinus (1978) found that bur oak, northern red oak, and black oak did not respond to longer photoperiods and concluded that high temperature was the key to extended growth.

D. CONTAINERS OR BAREROOT SEEDLINGS

Several studies have compared container-grown oak seedlings with bareroot stock. Some feel that containers in general offer advantages for producing tree seedlings because of the following:

1. The root system remains intact and undisturbed until planting and consequently there is less damage to it.
2. The container seedling has access to an external supply of water and nutrients unavailable to bareroot stock.
3. Containers have more rapid initial growth at the on-set of the first growing season.
4. There is an opportunity to extend the planting season for containers by artificially altering the environment that they're grown in.

P. Johnson (1979) evaluated container oak seedlings and 1-0 and 1-1 bareroot seedlings and reported that root growth and first-year shoot elongation were greatest for containers and least for the 1-0 bareroot seedlings. Container seedlings had a larger number of lateral roots, which provided numerous sites for initiation of growth. Dixon *et al.* (1976) also compared these two stock types and found lower moisture stress and greater elongation for container-grown plants. Kormanik *et al.* (1976), on the other hand, reported greater survival, height growth and root development for bareroot cherrybark oak seedlings than for containers. However, when this study was initiated in 1968, the techniques for growing seedlings in greenhouses were just being developed. Also, the container seedlings were only two months old compared to the one-year-old bareroot seedlings. Forbes and Barnett (1974) evaluated a number of hardwood species and reported no clear cut advantage of containerized seedlings with respect to growth and survival. They concluded, however, that containers "may aid in reforestation of disturbed areas (strip mining, etc.) and other poor sites by providing a better micro-climate for early development." Similarly, Tinus (1979) concluded that "container stock should be used for harsh sites where increased survival is needed".

In comparing the overall costs of container seedlings with bareroot, Tinus (1978) indicated that

> the costs . . . at the nursery gate may be similar for the two, but the container would be smaller. Container seedlings as large as a comparable bareroot seedling might cost four times as much. Container stock costs more to transport and handle because of additional bulk and weight. The actual planting, however, is usually easier and sometimes cheaper.

E. INSECTS AND DISEASES

There are a variety of insects and diseases that can attack oak seedlings both in bareroot nurseries and in greenhouses. A number of chemicals and culturing methods are used to control these pests and reduce their detrimental effects. In nurseries, fumigation is often used to control soil born insects, nematodes, fungi, diseases, and weeds (Williams and Hanks, 1976). The success of fumigation depends on a number of factors including soil moisture, soil texture, soil temperature, and organic matter content. The benefits of fumigation decrease with time because fumigated areas become contaminated from outside sources.

Among the major insect pests in bareroot nurseries are aphids and scale insects that feed on plant juices; grubs and nematodes which damage roots; and defoliators which remove foliage. Early detection and prompt control can help reduce the level of damage. Tinus (1978) warns that container-grown hardwoods require more protection against insects than conifers. He states that the best control for insects is to completely empty the greenhouse between crops and then fumigate. He also recommends using alternate insecticides to kill a wider spectrum of insects and retard the development of resistance.

Careful management of nursery soil is one of the first requirements for protecting the stock from disease (Williams and Hanks, 1976). Some of the more common diseases are damping off fungi, Anthracnose, root rots and powdery mildew. A specific oak disease reported to kill container grown northern red oak is *Cylindrocladium*. Oak and Triplett (1985) suggest a variety of techniques for controlling these species including a) avoiding using field soil as a growing medium, b) if field soil is used, fumigate it first, c) use commercial formulations of potting medium, d) avoid reusing potting medium from containers, and e) frequent reconnaissance of plant beds.

Shettler and Smith (1980) reported on some of the specific pests and diseases of native California oaks. They described several categories of pests including aphids and white flies which frequently occur in closely packed nursery blocks where much of the foliage is shaded; stem gall insects which can seriously damage seedlings by girdling twigs; powdery mildew, which can be a problem in late summer, primarily in sprinkler irrigated nurseries in foggy coastal locations; and fungus twig blights and root rots, which can generally be prevented by generous spacing and short duration, non-overhead watering.

F. MYCORRHIZAE

It has been documented that mycorrhizal fungi in tree nurseries have practical benefits for artificial regeneration programs (Marx, 1977). Mycorrhizae form a symbiotic relationship with seedlings--receiving carbohydrates from the host plant and providing an extended, absorbing root surface as a result of invasion of the host root system. The extended root system in mycorrhizal plants provides them with greater efficiency in water and nutrient uptake (Garrett *et al.*, 1979). While most of the production-oriented mycorrhizal research has focused on pines, there have recently been a number of research projects aimed at determining the effects of artificial inoculation with mycorrhizae on various species of oaks. These projects suggests that both bareroot and container oak seedlings may benefit from artificial inoculation with selected mycorrhizal species.

1. Factors Affecting Inoculation

There are many species of mycorrhizae that form relationships with the genus *Quercus*. Some, such as *Pisolithus tinctorius* form naturally on many plant species including pines and oaks. Others have a much narrower host range. However, it is clear that oaks can host a large number of mycorrhizal species. Dixon, *et al.* (1984) found that each of eleven isolates from five species of mycorrhizae colonized each of three different oak species. However, the authors found that there was great variability in the growth response of the seedlings depending upon the isolate they were inoculated with.

The species of host plant also greatly affects response. Even within a tree species seed source can make a difference. In a study with white oaks seedlings Marx (1979) reported that seedlings from five mother trees varied in their response to inoculation with *Pisolithus tinctorius* and concluded that "genetic variation in white oak regulated the amount of ectomycorrhizae found on seedlings and the amount of growth stimulation derived."

There also appears to be a strong interaction between mycorrhizae and other environmental variables. Mycorrhizae are sensitive to a whole host of conditions including soil nutrient status, pH, soil temperature, and presence of soil microorganisms. Pope and Chaney (1985) found a significant interaction between nitrogen and rate of inoculation for height growth, stem diameter and dry weight of seedlings. Dixon *et al.* (1980) found that soil temperatures significantly affected ectomycorrhizal development, with greater formation with increased temperatures. The lack of a growth response to mycorrhizal inoculation in a study by Kissey, *et al.* (1989) was attributed to overwatering.

2. Effects of Mycorrhizae

The actual morphological and physiological changes in oak seedlings inoculated with mycorrhizae include a wide array of characteristics. Results have varied for different studies and for different seedlings types (container versus bare root). Dixon, *et al.* (1980) reported that container-grown, *Pisolithus*-inoculated seedlings developed significantly greater numbers of roots, total root system lengths, and a greater proportion of unsuberized roots than uninoculated controls. They also reported substantial improvements in the mid-day values of the xylem pressure potential during a mild drought on the outplanting site. Pope and Chaney (1985) found significant increases in height growth, stem diameter, and dry weight as the amount of inoculum added to container red oak seedlings increased, although they also reported the percentage of seedlings colonized was erratic and not correlated with the rate of inoculation. Pope (1988) found that height and diameter of inoculated red oak seedings produced in fumigated nursery beds were larger and the number of saleable seedlings increased after inoculation. He also reported more fibrous root systems and higher concentrations of carbohydrates. However, not all results have been positive. Kissee *et al.* (1989) found that early development of mycorrhizae on inoculated container grown seedlings provided little growth advantage.

It has been more difficult to document the beneficial effects of inoculation on outplanted seedlings than for those grown in closely controlled environments such as growth rooms or fumigated nursery beds. This may be due to several factors. First, the degree of variability at outplanting sites is generally much greater, thus making it more difficult to statistically demonstrate differences between treatments. Second, native mycorrhizae at outplanting sites may mask the effects of the inoculation treatments by rapidly colonizing outplanted seedlings. For instance in a recent study comparing inoculated container with uninoculated bareroot seedlings, excavation after outplanting revealed all treatments were mycorrhizal by the spring following planting (Crunkilton *et al.*, 1989).

Several studies have reported improved field performance for inoculated seedlings. Parker *et al.* (1986) found that mycorrhizal black oak seedlings were taller than non-inoculated seedlings for the first two years after outplanting. However, during the next three to four years, both types grew at comparable rates. Specific mycorrhizal species may improve the performance of seedlings more in one type of environment than in another. For instance Kissee *et al.* (1989) reported that while *Pisolithus*-inoculated English and black oak seedlings appeared to perform best in the greenhouse, *Suillus*-inoculated plants generally performed better after they were outplanted.

3. Use of Mycorrhizae on California oaks

The literature on mycorrhizae from other locations suggests that artificial inoculation is a promising approach for improving regeneration success with California oak seedlings. This appears to be a particularly important area for research since one of the major limiting factors for successful seedling establishment in the dry Mediterranean-like environment of California is limited soil moisture. Previous studies have shown that mycorrhizae can improve moisture uptake and the moisture status of seedlings in dry soil conditions. The challenge is to determine which particular species or isolates will work well for the California oak species being produced.

G. VEGETATIVE PROPAGATION

While planting acorns or seedings is by far the most common method of regenerating oak seedlings in California, some have suggested that vegetative propagation may be desirable in certain situations. Vegetative propagation offers the opportunity to produce uniform, genetically superior plants selected for traits such as disease or drought resistance. At present, however, this advantage is largely theoretical since little is known about the genetic variability of native California oak species.

Another potential advantage of vegetative propagation in that it does not depend upon acorns. As indicated previously, acorn crops are highly variable over time, between species and trees within species, and from one site to the next. Since acorns generally can't be stored for more than one season, poor acorn production often hinders both direct planting of acorns and seedling propagation. Successful vegetative propagation would overcome this limitation.

1. Cuttings

The most widely tested method of vegetatively propagating oaks is through rooted cuttings. While it is generally recognized that oaks are difficult to propagate this way, there have been numerous studies throughout the world with a wide variety of oak species. Most of the success can be attributed to combinations of using cuttings from young plants, growth regulators, and moisture (Davis, 1970).

Even though younger plant material has generally proven easier to root, results have varied depending upon the origin of the material and the species tested. For instance Duncan and Mathews (1969) found that for water oak, cuttings from stump sprouts rooted better than cuttings from branches. However, for southern red oak (*Quercus falcata* michx. var. *falcata*) just the opposite was found. The authors also found that stump sprouts of water oaks were relatively easy to root while several other species they tested proved much more difficult. They concluded that diameter and age of wood to be used as cuttings is of great importance and recommend using sprouts that are large

(1/4 inch or larger) taken from the first flush after it hardens off just prior to the second flush.

Others have had good success with even younger plant material. Isebrands and Crow (1985) reported that softwood cuttings of three-week old northern red oak were successfully rooted in the greenhouse. In an experiment evaluating a variety of environmental variables, they had an average rooting of 88% for all of their treatments and stated that the young age of the cutting was an important factor since previous attempts at rooting more lignified cuttings were much less successful.

Davis (1970) successfully rooted softwood cuttings of shrub live oak (*Quercus turbinella* Greene). He found that both soft fully expanded and hardened cuttings were superior to succulent cuttings in the elongation stage, and felt the success of the experiment was related to close control of environmental conditions in the rooting chamber, including high humidity, intermittent mist, controlled air and root temperatures, and adequate light.

Morgan (1979) examined a number of variables related to the rooting of Texas live oak seedlings. He reported the time of year when cuttings were collected influenced rooting ability, with failure to root for those collected in the cold winter months (November to March). He also stated that in general the younger the plant, the greater the rooting success. Cuttings from 5 to 8 year old seedlings rooted poorly compared to those from younger ones.

Hare (1977) evaluated the rooting ability of water oak and found that by girdling branches six weeks prior to harvesting the cuttings from the trees, rooting response could be greatly increased (20 to 76 percent). The girdling apparently promoted rooting by channelling photosynthate into the production of callus and roots. He did caution to harvest cuttings before too much callus has formed, since large amounts of callus appeared to inhibit rooting.

Treatment of cuttings with the hormone indolyl butyric acid (IBA) is commonly used to stimulate rooting. Duncan and Mathews (1969) found that IBA and a fungicide increased rooting of oaks when compared to an untreated control. Similarly, Isebrands and Crow (1985) reported that treatments having no IBA had significantly fewer roots. Morgan (1979) also concluded that hormone application is essential with concentrations of 10,000 ppm of IBA and higher the most effective for Texas live oak. However, Davis (1970) applied IBA as a foliage spray in a rooting chamber and found no increase in rooting of shrub live oak as a result of this treatment.

2. Grafting

Grafting has also been suggested as a means of establishing commercially important species such cork oak (*Quercus suber*). Mirov and Cumming (1945) reported that in Europe, cork oak has been successfully grafted to a variety of oak species. Different ages of root stock have been used including two year old seedlings, stump sprouts, and branches of mature trees. Experiments conducted in California in the forties showed that cork oak species could also be successfully grafted to the seedlings and tree branches of a native California species - canyon live oak. Shettler and Smith (1980) also reported limited success with a simple side graft performed in January for coast live oak. In a very recent study, Tietje *et al.* (1990) reported successful grafting of blue and valley oak scions onto blue oak rootstock.

3. Tissue Culture

In vitro plantlet regeneration of several oak species has been reported, although the technology for this approach is still being developed. Shoot cultures of *Quercus robur* have been established and multiplied *in vitro* using original material from both juvenile seedlings and stump sprouts from mature trees (Vieitez *et al.*, 1985). *In vitro* regeneration of two Japanese oak species was also successfully accomplished using short, nodal segments with axillary buds isolated from two month old seedlings (Ide and Yamamoto, 1986; Ide and Yamamoto, 1987).

H. EVALUATING SEEDLING QUALITY

It is generally agreed that the quality or vigor of seedlings at the time of planting can have a profound impact on their field performance. It is not clear, however, how to grade seedlings in the nursery or greenhouse or how to measure this characteristic.

1. Morphological Criteria

Some have suggested that morphological grades for oak seedlings can enhance outplanting success by identifying and discarding seedlings that have little chance for acceptable field performance. Stroempl (1985) outlined grading criteria for northern red oak based on a number of shoot characteristics for 2-0 nursery stock. He recommended only using seedlings with a caliper of at least 4.5 millimeters, a stem length of 30 centimeters, a straight and well defined shoot, and numerous buds. Kormanik and Ruehle (1987) also recommended planting only seedlings exceeding minimum above ground standards; but they also suggested that plants have a minimum number of first order lateral roots. For northern red oak, they estimated that using the appropriate standards, 60 percent of the seedlings currently produced would be culled. While they recognized that a seedling's ability to produce such roots is under strong genetic control, they felt that certain nursery culturing conditions such as seedbed density could be modified to enhance a seedling's ability to produce strong lateral roots. In a detailed experiment evaluating the number of such roots, Ruehle and Kormanik (1986) found a strong correlation between lateral root development and height, stem diameter, top weight, and root weight.

Larson (1977) evaluated autumn shoot characteristics of northern red oak seedlings in a nursery bed to determine if autumn leaf color and retention, leaf area, and number of growth flushes were related to field growth for seedlings planted the following spring. Green foliage in the early fall was correlated with greater subsequent growth, as was the number of flushes in the seedbed. Larson also found that spring growth was closely related to seedling weight at the time of planting and concluded that the problem of poor early growth for this species may be partly overcome by using large, vigorous stock.

2. Root Growth Potential

Another commonly used method of evaluating seedling quality is to measure root growth capacity (RGC), or root growth potential (RGP). To measure RGP, seedlings are placed in a standard environment for a specified period of time (usually 28 days). Afterwards, the root systems are evaluated for the number and/or length of new white elongating roots (Ritchie, 1985). This method is based on the premise that seedlings that have high RGP have a better chance of surviving and growing when they are outplanted since they are better able to take up moisture and nutrients. This approach has been used extensively to evaluate conifers but there have been relatively few studies on the RGP of oaks. The work that has been done suggests that high RGP values are associated with better field performance. Lee *et al.* (1974) reported that pin oak had greater RGP than scarlet oak and concluded that this was one of the principal reasons why pin oak was easier to establish. Webb and von Althen (1980) reported that first-and second-year survival and growth of outplanted red oak seedlings were significantly correlated with RGP. Farmer (1975) also found that RGP was closely correlated with new shoot development of northern red oak. He concluded that "large planting stock, with high levels of food reserves and adequate chilling, have the physiological capacity of quickly regenerating new root systems sufficient to support vigorous shoot growth and expansion of leaf area." He suggested that environmental controls and planting techniques should be aimed at getting root growth underway before the plants come under moisture stress.

A final method of stimulating root regeneration and improving field performance has been studied by Larson (1988) and Hartwig and Larson (1980). They both found that both RGP and field performance could be markedly improved by treating seedlings with growth hormones prior to planting.

IV. SITE PREPARATION AND PLANTING

A. INTRODUCTION

A search of the literature produced numerous oak planting studies conducted in the eastern United States and a few from west of the Rockies. This review focuses on studies done in the United States on site preparation and planting techniques for several oak species. Whenever possible, studies conducted in other parts of the United States are related to known conditions for planting oaks in California. The material is divided into two sections: Site Preparation and Planting Techniques for both direct seeding of acorns and transplanting seedlings.

B. SITE PREPARATION

1. Planting Sites

Degree and methods of site preparation are dictated by soil and the type and density of vegetation at the planting site. Species should be matched as closely as possible with a suitable site (Kennedy, 1981). Habitat requirements vary greatly between oak species. Some species of oak can withstand a broad range of site conditions, whereas, other species cannot.

Each planting site has unique requirements in regards to species and soil characteristics. In the South (R. Johnson, 1984), cherrybark oak grows best on well-drained bottomland sites, whereas swamp chestnut oak (*Q. michauxii Nutt.*) grows on poorer quality sites (Seifert *et al.*, 1985). In Georgia, sites with soils that are deep sandy loam to silty loam work well for planted southern red oak (Vande Linde, 1987). In the Missouri Ozarks, mid to lower north- and northeast-facing slopes are generally good sites for planted northern red oaks (P. Johnson *et al.*, 1986). In the central coast regions of California, live oak, blue oak, and valley oak can all be found on dry, loamy or gravelly soils (Sudworth, 1908). However, the valley oak prefers alluvial terraces, whereas live oak prefers north slopes with deep soils (Barbour and Major, 1977). Blue oak prefers the deep rocky soils, but the actual location of blue oak in the woodlands is dependent on local soil conditions.

Griffin (1971) has observed that slope exposure influences survival of oak seedlings in California. Of three species of oak studied, blue, valley, and coast live oak the former is the most drought tolerant, but in grass cover on a south-facing slope, even seedlings of this species could survive their first summer only during wet years. On north aspects, seedlings of several species survive grass competition over a broader range of climatic conditions.

Most oak seedlings will not survive more than a few years under crown cover (overstory or understory) that allows little light to reach the forest floor (Sander *et al.*, 1983; McGee 1975). Survival and establishment of advance oak regeneration, represented by oak coppice and containerized nursery stock, was improved by either thinning or total understory vegetation control with herbicides, but the combination of the two cultural treatments improved survival and growth of nursery stock even more (Wright *et al.*, 1985). Unless the understory of woody plants is controlled, reducing overstory density by shelterwood cuttings may not enhance development of oak reproduction (Beck, 1983; Sander, 1979). Lack of aggressiveness dooms most seedlings (Clark, 1970).

Shelterwood (partially cleared) conditions are recommended over clearcut (completely cleared) conditions for planting seedlings in forested areas of the South (R. Johnson, 1984). Planting under a shelterwood can imitate the natural occurrence of advanced reproduction in the understory so that competing vegetation is kept down while seedlings establish root systems (Nix *et al.*, 1985). In the Missouri Ozarks, planting under a 55 to 60 percent stocked shelterwood creates appropriate lighting for seedling growth, but not enough light for growth of competing vegetation (P. Johnson *et al.*, 1986). However, reduction of overstory through the shelterwood cutting system for enhancement of red oak (*Q. rubra*) regeneration in Wisconsin increased the density of the competing shrub layer (Auclair and Cottam, 1971). As shrub density increases, populations of tree seedlings tend to decrease (P. Johnson, 1976; Loucks and Schnur, 1976).

Response to overstory is variable among California oaks (Jepson, 1910; Sudworth, 1908). In their examination of factors associated with oak regeneration in California, Muick and Bartolome (1987) found 95% of interior live oak seedlings growing beneath canopies but less than two-thirds of blue oak seedlings in this position. The remainder of the blue oak seedlings were either at the edge of canopies (about one-third) or in the open (7%). In this study, most blue oak saplings occurred at the canopy edge or in the open while saplings of interior live oak occurred more commonly beneath canopies.

2. Methods of Site Preparation

There are many different methods of site preparation, and each author has a preference. Some authors (Brenneman, 1977; Wright *et al.*, 1985) believe that site preparation on cutover lands in the South should include removal of unwanted hardwoods and brush. On steep sloped forested areas, Russell (1971) feels that herbicides used with a mist blower are most effective for initial control of competing vegetation. However, it rarely produces 100 percent control and slow-growing oak seedlings can become out-competed within 3 to 4 years. Russell goes on to say that disking and chopping can produce a more thorough and longer lasting control than with the herbicides. Blading is not recommended because it can strip topsoil. On old fields (i.e., fields previously in crops), Erdmann (1967) recognized that herbicides are the most effective means of weed control. Weed control is important because of the slow height growth of oak seedlings. It eliminates competition for moisture and important nutrients which give the seedling a head start (Nix *et al.*, 1985). Rodents become less of a problem when their preferred habitat is removed (Godman and Mattson, 1985).

In the South, direct seeding on old fields works better on thoroughly prepared sites (Johnson and Krinard, 1987; Seifert *et al.*, 1985; Wright, 1985). This may be accomplished by burning herbaceous weeds, single disking, cross disking plus soil pulverizing, or with herbicides. In California, Welker and Menke (1987) suggest that dry conditions in blue oak communities, resulting from dense annual plants, may be the principal cause of limited seedling establishment. They conclude that these communities are apparently more xeric today than before the arrival of European man, livestock, and the development of grazing practices that contributed to high annual plant densities and reduced litter. Widespread grazing during the past 200 years has produced a shift in dominance of understory vegetation in blue oak communities from perennial bunchgrass to annual grasses and taprooted forbs. This change has apparently resulted in a different water use pattern and altered soil moisture conditions that make it much harder today for seedlings to become established.

Severe competition is believed to also limit artificial blue oak regeneration in California (Chan *et al.*, 1971). Adams *et al.* (1987) reported that no seedlings developing from planted blue oak acorns survived in Yuba County beyond the middle of the first season without weed control. During a severe drought in 1968, Griffin (1971) reported that all blue oak seedlings planted in grass died, compared to 100% survival in areas where the grass was cleared. In central California, however, intensive site preparation does not always seem necessary prior to planting oaks (Bill Weitkamp, pers. comm.). In fact, dried weed beds may be preferred to bare soil for planting in some instances because they provide a mulching effect which helps maintain soil moisture. On the other hand, cleared sites can have lower surface temperatures; when surface temperatures are higher than 50 degrees F., germination falls off rapidly (Godman and Mattson, 1985). The above results suggest that the level of site preparation is apparently determined by the different soil types and weather patterns in the United States

a. **Hand Control.** Site preparation using hand methods is not often used in the Southern and Eastern states. In general, methods such as hoeing are too slow and expensive to be practical. Furthermore, a regeneration study done on northern red oak (Scholz, 1955) showed no significant difference between site preparation using a mattock hoe and an Athens disk.

b. **Mechanical Control.** Mechanical site preparation methods such as blading, chopping, disking, and bedding are used to control competition of weeds when planting in the South and East. A study by Vande Linde (1987), suggests a site preparation of two complete harrowings (cultivating process for breaking up the soil) with a heavy duty disk harrow is necessary for establishment of oak plantations. In Mississippi (Francis, 1983), water infiltration was increased on eroded ridges by constructing contour ditches, 2 feet deep and spaced 10 feet apart, with a dozer blade.

Several studies recommend disking prior to planting for extensive control of weeds (Krinard and Francis, 1983; Vande Linde, 1987; Johnson and Krinard, 1985). Disking prior to planting encourages water percolation and increases air circulation which in turn stimulates growth (Nix *et al.*, 1985). Disking also reduces competing vegetation during the first growing season. A study done with swamp chestnut oak shows that disking and bedding, on a poorly-drained site, increases both seedling diameter and height growth (Seifert *et al.*, 1985).

c. **Chemical Control.** In forested areas, woody vegetation smaller than 2-inch diameter can be controlled by applying a herbicide (Wright *et al.*, 1985). During the dormant season, 2, 4-D plus picloram can be used on cut stumps and in stem injections (P. Johnson *et al.*, 1986). During the growing season, roundup can be applied with a hand sprayer (P. Johnson *et al.*, 1986). Seifert and Fischer (1985) controlled 97 percent of the woody vegetation and 100 percent of herbaceous cover with Roundup applied with a mist blower.

According to Wright (1985), the rates of chemicals used in site preparation should only be strong enough for one growing season. Larger doses could kill or injure the planted seedlings. Triazine was occasionally found to cause interveinal chlorosis and leaf curling to planted northern red oak and white oak seedlings (Wright, 1985). Using a mist-blown herbicide such as glyphosate plus triclopyr on competing vegetation allows adequate establishment of planted seedlings (Wright *et al.*, 1985). Seedling survival can be insured, while keeping weed control adequate, by using the appropriate herbicides. The best time to apply a contact herbicide is during the spring, before the oaks leaf out. The best time to apply soil-active herbicides is during the winter, so they can wash into the soil (D. McCreary, Pers. Comm.).

d. **Fire.** Although loss of litter is seen as a problem in California, it is not viewed in the same way in the eastern United States. Sander *et al.* (1983) observed that acorn germination is not inhibited by light litter, but seedlings may not be able to emerge through a heavy litter cover. Prescribed burning is a potential way to control vegetation and litter, and burning generally promotes vigorous growth of seedling sprouts in the East (Hannah, 1987). Carvell and Tryon (1961) found that partially cut, highly burned or grazed stands had the most advanced oak reproduction.

In the north central states, fire played an important role in the establishment of existing oak stands (Sander, 1977). The recurrent fires that followed cutting of the original timber stands nearly eliminated less fire-resistant species. Oaks survived because of their ability to sprout repeatedly. Development of the present oak stands followed fire protection and control of widespread burning.

Although fire was a prime factor in the development of oak stands in the north central states, its use as a silvicultural tool for regenerating oak cannot be recommended (Sander, 1977). Oaks are susceptible to damage by fire at all stages during a rotation, and many of the cul trees in present oak stands were damaged by fire.

e. **Rodent Control.** In the eastern U.S., rodents are considered the chief obstacle to reproducing oaks from seeded acorns (R. Johnson, 1979; Krajicek, 1955). The best protective method employs screens of hardware cloth to cover planted spots (Stoeckler and Scholz, 1956). However, no protective measure (season of planting, screens, or repellents) was considered good enough in 1954 to be recommended for general use (Nichols, 1954). In 1983, Sander *et al.* reaffirmed the need to protect directly seeded acorns and the lack of success in using repellents.

Seeding of Nuttal oak acorns in forest openings greater than 100 feet on a side reduced rodent damage (R. Johnson and Krinard, 1987). The acorns used in these Mississippi studies were sown soon after collection, and this practice may impart an advantage; the investigators theorized that, compared to stored acorns, newly collected acorns do not exude odors attractive to rodents. Of acorns sown, they suggest that 35% should be able to establish seedlings in commercial plantings. Earlier work reported by Johnson and Krinard (1985) identified forest openings 2 acres or larger in size as necessary to reduce loss of acorns to rodents. Changes in small mammal behavior in response to habitat manipulation have been well documented. Reduced rodent damage discussed above depends on the tendency of some small mammals to avoid open spaces (Birney *et al.*, 1976; Price, 1978; O'Dowd and Hay, 1980). Seedbed scarification can reduce depredation from rodents by eliminating favorable habitat and cover (Godman and Mattson, 1985). In Wisconsin, planted acorns were undisturbed by rodents on a scarified site, whereas on a nearby untouched area the acorns were depredated. Heavy depredation depends on the type of rodent and the time of day they are active.

In California, it is believed that the changes in vegetative composition during the last 200 years may have created habitats that now support larger populations of predators that attack oak vegetation. The relationship between competition and predation is clear in the eastern United States (Wright, 1985).

C. PLANTING

1. Planting Stock

a. Direct Seeding. Direct seeding of oak acorns has advantages over planting seedlings. Costs are lower: there are no nursery expenses and labor for planting is less expensive (Brenneman, 1977). Direct seeding allows the root system to develop naturally, without disturbance from transplanting (McElwee, 1970). Adaptation to conditions less favorable than those of a nursery is also unnecessary.

Germination of acorns planted in the field was nearly 90 percent for Nuttall oaks planted in the south (Johnson and Krinard, 1987). In Mississippi (R. Johnson, 1984) field germination for planted shumard oak acorns was 55 percent. Generally in the Southern states, the red oaks (nuttall, shumard, cherrybark) seem to germinate better than the white oaks (swamp chestnut, willow, bur) (Johnson and Krinard, 1985). Germination can also be high for California oaks. McCreary (1989a) reported over 90 percent germination and first year survival for both blue and valley oak seedlings, when planted before March.

Planting depth affects oak germination and survival. Nuttall and water oak acorns were planted at 2-, 4-, and 6-inch depths (Johnson and Krinard, 1985). Germination started about the same time at all depths, but the acorns planted 2-inches deep had a 20 percent better germination rate. Emergence time was similar at 2- and 4-inch planting depths but somewhat later for 6-inches, and acorns planted 2-inches deep produced 10 percent more seedlings than those planted 4- or 6-inches deep.

b. **Transplanting Seedlings.** Numerous planting studies in the Southeast compared container-grown seedlings with bareroot seedlings. According to Kormanik *et al.* (1976), bareroot cherrybark oak seedlings had larger, more extensive root structures than container-grown seedlings. On the other hand, English oak (*Q. robur*) seedlings grown in open-bottom containers produced better root structures than bareroot seedlings. However, the diameters of the bareroot seedlings were slightly larger at the time of planting (P. Johnson, 1981). After three years, the bareroot seedlings were growing at a better rate than the container-grown seedlings. Similar results were found with northern red oak (Wright *et al.*, 1985). Two years after planting, container-grown seedlings were growing at approximately the same rate as the bareroot seedlings. These data show that bareroot seedlings may be better for transplanting than container-grown seedlings.

Container-grown seedlings have less disturbance to the root system than bareroot seedlings because they are lifted with a soil ball attached to the roots. In West Virginia, roots of northern red oak bareroot seedlings were disturbed, but their survival rate was over 40 percent higher than for container-grown seedlings (Wendel, 1979b). This indicates that disturbance to the roots does not hinder survival.

Seedling vigor has a strong effect on early growth and survival. Early growth is necessary to out-compete surrounding vegetation (Nix *et al.*, 1985). Large-diameter seedlings seem to produce healthier trees than smaller-diameter seedlings (P. Johnson *et al.*, 1986; Kennedy, 1981). Optimal growth and survival was achieved with 3/8-inch diameter seedlings.

2. Planting Season

The time to plant oak acorns and seedlings depends on the geographic area and local weather conditions. In areas where the soil freezes, planting should be done in spring. Planting can be successful in the summer if local temperatures are moderate and adequate rainfall is typical. In the southern United States, planting can be done anytime of the year as long as the soil moisture is adequate. Johnson and Krinard (1987) planted nuttall oak acorns during all months of the year and found germination successful for each month. The lowest germination rate (50 percent) was for acorns planted in September. The best results came from acorns planted in early winter. In California, the best planting results occur when acorns are planted in late fall or early winter, following a heavy rain (W. Tietje, W. Weitkamp, pers. comm.). This allows adequate time for seedling establishment and tap root development before the hot, dry season of summer starts. McCreary (1989a) reported that both blue and valley oak acorns planted in March had later emergence and lower survival and height growth than acorns planted the preceding four months. The earliest emergence was for acorns planted in November.

Similar results were reported for California black oak seedlings planted during the fall and spring in the chaparral of southern California (Roberts and Smith, 1982). The seedlings planted in the fall had a better survival rate and better growth after one year than the seedlings planted in the spring. Fall plantings were more successful because the seedlings adjusted better to transplanting during fall dormancy than during the growing season in spring.

Acorns planted immediately after collection may have less depredation from animals. When acorns are stored they exude an odor which may attract animals once they are planted in the ground (Johnson and Krinard, 1987). R. Johnson (1984) found that acorns planted in spring had a higher depredation rate than those planted in fall. Furthermore, if acorns are planted immediately following collection, there are no storage or monitoring problems to deal with. Although acorns planted soon after collection have less depredation and minimal storage problems, germination may be less than stored acorns. For example, D. McCreary (pers. comm.) found that blue oak acorns stored for 4-8 weeks in a refrigerator had faster and more complete germination than unstored acorns.

3. Planting Methods

a. Planting Tools. Methods for planting oaks vary considerably, running from simple hand tools to complicated machines. Site factors such as soil, size of area, topography, and density of existing vegetation, along with financial constraints, determine whether to plant by hand or machine. Hand tools have an advantage of more flexibility with respect to planting depth. Acorn planting machines have a disadvantage of malfunctions, such as not dropping acorns for long distances. The mattock center hole method can be used on rocky sites or when large seedlings are being planted (Russell, 1973). The bar-slit method can be used on most soils, and is better adapted for normal-size seedlings (Nix *et al.*, 1985). In Tennessee, northern red oak showed no significant difference in growth or survival for plantings done with either method (Russell, 1973). When using the bar-slit method, seedlings should be root pruned prior to planting to prevent the tap root from curving up.

Old fields in the south have been direct seeded using modified soybean planting machines (Johnson and Krinard, 1987). Soil moisture can be a limiting factor for machine planting. The soil might not be dry enough for the machine until the growing season has started. The authors expect a 35 percent success rate from this type of commercial acorn planting.

b. **Augering**. Hard compacted soils can make it difficult for roots to penetrate deeply, resulting in less access to moisture later in the growing season as the soil dries out. Tworkoski *et al.* (1983) evaluated the effects of soil texture and bulk density on white oak seedling growth and found that at bulk densities of 1.5 gm per cubic centimeter, root growth was significantly reduced. Soil auguring can be used in areas where the root system would not be able to penetrate the soil easily. Studies in northern California have shown favorable early growth for blue and valley oak seedlings planted in augered holes (McCreary, 1989a).

c. **Spacing.** Requirements for spacing seem to differ with the individual study being conducted. Vande Linde (1987) concluded that 10 x 10 foot spacing is the minimum necessary for oak trees. R. Johnson (1984) feels that for direct seeding, a smaller spacing (4 x 9 feet) is better in most situations since certain microclimates are more favorable to acorn establishment. Planting the acorns close together makes it more likely that favorable sites will be selected. However, the oaks will have poor results if the acorns are planted too close together. A spacing of 2 x 10 feet produced trees that were only 2-inches DBH 11 years after planting (Johnson and Krinard, 1985). The authors concluded that the spacing was too close for favorable stem growth. Current studies in central California have produced satisfactory seedling establishment with a spacing of 2 to 5 feet (W. Weitkamp, pers. comm.). Weitkamp observed that during the first few years of growth, the seedlings have not shown evidence of intraspecific competition.

d. **Mulch.** Seedlings can be protected from competing vegetation by mulching. Among the different techniques, black plastic is the most common (P. Johnson, 1981). Poor results occurred with the growth of English oak seedlings because the plastic did not allow enough soil moisture to reach the seedlings. Natural vegetation can also be used for mulching. A local rancher (D. Martter, Pers. Comm.) in central California used litter and duff from beneath mature oak trees as a mulch for the seedlings he planted. He had no problems with competing vegetation with this method. It probably works because the high acid content of the oak litter is too strong for competing vegetation to become established.

e. **Fertilizers.** The use of fertilizers at the time of planting works well for establishing conifer plantations and should work well for hardwoods. In the East tave been numerous studies on use of fertilizers (Dunn, 1980; McElwee, 1970; Woessner,

1977) but they have not been duplicated in California. The eastern studies show a positive response from the use of certain fertilizers. A slow-release fertilizer, magnesium ammonium phosphate, significantly increased the heights of black oak and scarlet oak seedlings (P. Johnson, 1980b). Fertilization of planted northern red oak seedlings has improved growth in some instances, but gains generally have not been large enough to justify the added cost (Foster and Farmer, 1970). In California, McDonald (1979) observed that the growth rate of black oak and tanoak (*Lithocarpus densiflorus*) seedlings increased with applications of fertilizer containing nitrogen and phosphorous. He also found that fertilized black oak seedlings suffered less moisture stress in September when maximum stress occurs.

Use of fertilizer may not always be beneficial. Adams *et al.* (1987) found that a slow release fertilizer placed beneath acorns at planting depressed emergence of blue oak and valley oak where weed control was not practiced. In this study, survival at the end of the first growing season was greater for unfertilized blue oak regardless of weed control and greater for unfertilized valley oak growing with weeds. Survival of transplants of both species in this study was depressed by fertilization. Survival of transplants of both species was also depressed by addition of fertilizer beneath seedlings.

f. **Irrigation.** Growth of oak regeneration is further limited due to moisture stress created by competition. Larson and Whitmore (1970) observed that shoot growth, root growth, and the number and diameter of vessels in the stems of red oak decreased as the soil water potential decreased. They also observed that bud break was delayed by moisture stress. Studies conducted with white oak by Teskey and Hinckley (1981) supported these findings. When favorable soil temperatures occurred under field conditions, root elongation rate, number of growing roots, and root growth intensity (the sum of projected root area compared to the total root viewing area in a rhizotron) were reduced dramatically when predawn leaf water potential dropped below -0.5 MPa.

If soil moisture is low, acorns and seedlings should be watered thoroughly when planted. After planting, watering can be done anywhere from once a week to three times a year, depending on the site. In California, numerous studies are underway to determine the effects on growth of watering oak seedlings. In southern California, spring-planted seedlings were watered once a week with 2 liters of water (Roberts and Smith, 1982). The irrigation did not produce any significant growth differences. The authors feel the lack of growth was due to insufficient watering, however, more frequent irrigation would not be financially feasible for that location. On the other hand, a study with valley oaks in northern California has shown significantly increased growth from frequent irrigation, but no difference in survival (McCreary, 1989b). Interestingly, there were no significant differences in height growth between a control, and seedlings watered with one gallon once or twice a month. McCreary concluded that little supplemental water was needed to establish valley oak seedlings as long as the planting spots were augered and fertilized, there was good weed control, and there was sufficient moisture-holding capacity in the soil.

4. Costs Associated With Planting

Planting and site preparation costs vary, depending on the methods chosen. Extensive site preparation can be expensive. Costs of completely clearing a site can be as high as $200 per acre (Kennedy, 1981). Direct seeding can be simple, quick, and inexpensive since there are no nursery costs. Because of the slow early growth associated with direct seeding, however, costs may run high depending on the time needed to control surrounding vegetation. For Johnson and Krinard (1987), hand planted acorns cost $45 per acre. Machine planting 40 to 100 acres of acorns, in a 6- to 8-hour period, cost $6 to $15 per acre. Planting seedlings is costly because of nursery expenses. The costs for planting seedlings were twice that of planting acorns (Johnson and Krinard, 1987). Container-grown seedlings cost more than bare root seedlings, but may not grow any faster or be healthier.

D. CONCLUSIONS

Maintaining current distribution and abundance of California native oaks depends on effective management strategies, including affordable and successful methods of artificial regeneration. Problems, including cost, associated with site preparation can be reduced by recognizing the proper method for the individual site and matching that with management objectives. A major problem associated with successful oak planting appears to be the slow growth rate of young seedlings. This problem could become less severe with improvements in planting stock, competition controls, irrigation methods, and the use of fertilizers. Another common problem is depredation of acorns and seedlings from small mammals. Inexpensive ways to protect the seedlings need to be developed, along with dependable repellents.

Research on artificial regeneration seems abundant in the eastern and southern United States. In California, current literature is rather limited. There are, however, numerous planting studies underway in California. These studies need to be published, in order to help others achieve successful planting projects.

With proper techniques, planting oak trees as a way to help natural regeneration is possible. Site-specific information is essential because each planting location has its own particular attributes. Recognizing these characteristics, and adjusting the planting methods accordingly, will help ensure successful oak tree planting.

V. ACORN AND SEEDLING PROTECTION

A. INTRODUCTION

Acorns are an important source of food for many insects, birds, and mammals. For example, Bowyer and Bleich (1980) observed that 85% of the California black oak acorns dropped in 1978 on the Cuyamaca Mountains were consumed by wildlife over a three week period, with 94% of these acorns consumed by mule deer. This pattern is repeated throughout California for all species of oaks, although the relative proportion of the acorn crop eaten by the various acorn predators may differ. Acorns provide a concentrated source of energy to the consumer, and animals ranging in size from black bears to deer mice utilize them to varying degrees.

Oak seedlings are also consumed by a variety of herbivores. At the Hopland Field Station in Mendocino County, Menke and Fry (1980) found that black-tailed deer diets were composed of 40% oak browse (leaves and twigs) in the summer months (oak browse plus acorns made up 59% of the diet). They noted that year-long consumption of oak browse averaged 21.5% per month. Nitrogen levels in both blue and California black oaks peaked in the spring (May), and they speculated that oak browse was a significant source of crude protein for deer. Although the majority of this browse must have been leaves and twigs from the lower branches of larger trees, oak seedlings within the reach of deer are no doubt consumed also. Other animals, such as pocket gophers and sheep, consume seedlings as well.

Thus, it comes as no surprise that professionals involved in the planting of oaks in wildlands invariably include some management strategy which is directed toward reducing predation or herbivory on planted acorns and seedlings. The same mortality sources which affect naturally planted acorns are present in the environment and affect human-planted trees. In order to maximize survival and minimize replanting costs, appropriate protection methods must be utilized.

B. ACORN MORTALITY SOURCES

1. Insect Mortality Sources

Acorn mortality from insects occurs both on the tree and on the ground. Thus, acorns can be damaged prior to collection and storage, resulting in the planting of damaged acorns, or acorns can be damaged in the ground following planting. A detailed review of insect damage to acorns in southern California was written by Brown and Eads (1965).

Insects are a major threat to regeneration in the eastern United States. In parts of Pennsylvania, the primary cause of regeneration failure after harvest cutting or natural disturbance is lack of viable acorns, a result of destruction by acorn insects and rodents (Marquis *et al.*, 1976). Acorns are seriously damaged by weevils (*Curculio* spp.) (Arend and Scholtz, 1969). At least 60% and more often 90% of fallen acorns are infested, and this greatly increases the difficulty of obtaining natural regeneration. In southern Appalachian oak stands, two groups of insects, nut weevils and gaul insects, cause the largest losses of acorns (Beck and Olson, 1968).

Bonner and Vozzo (1987) reviewed insect predators to acorns for the genus *Quercus* in North America. *Curculio* species were considered major pests. These insects deposit their eggs in acorns, and the larvae feed on the cotyledon tissue. They noted that the filbertworm (*Melissopus latiferreanus*) was responsible for "...severe destruction to acorn crops, particularly during poor crop years..." (p. 10). The larvae of the warehouse moth (*Ephestia* sp.) and acorn moth (*Valentinia glandulella*) are also known to feed on acorns. Vozzo (1984) found fungal isolates from the head, gut, and carcass of *Curculio* larvae. He questioned whether these insects could act as vectors or sources of fungal contamination to acorns. Galford (1986a) discovered that, contrary to other published accounts, acorn moth (*Valentinia* spp.) larvae were primary invaders of sprouting white, red, and chestnut oak acorns. Previously, it had been believed that these larvae infested only acorns damaged by rodents or other insects.

In California, insects destroy a significant number of acorns. Roy (1962) reported that one study found insect larvae infesting 51% of acorns. Brown (1980) reported that as many as 80% of collected acorns may be infested by insects. In California, the two most common acorn-boring insects were the filbertworm and the filbert weevil (*Curculio occidentis*). Damage may be either the destruction of the embryo or the depletion of the cotyledons, resulting in a reduction of the vigor of a new oak tree. The filbertworm is distinguished from the filbert weevil by the true legs on the thoracic segments and prolegs with tiny hooks on the abdominal segments, while the filbert weevil larvae is legless. In an evaluation of potentially parasitized acorns collected from most of the range of oak in the United States, no acorn-infecting weevils of the genus *Conotrachelus* were found in samples submitted from California, although these acorn inhibiting curculionid weevils are known to breed in acorns elsewhere in the United States (Gibson, 1964).

Griffin (1980) determined that 21% of valley oak acorns over an 8 year period were not viable due to insect damage, mainly due to the filbert weevil and the filbertworm. Seasonal losses ranged from 0 to 31%. McElwee (1970) reported that acorns collected from the ground after normal seedfall in North Carolina contained a high percentage of weevil-damaged acorns, especially among those falling first.

Knudsen (1987), studying valley oak in Sutter County, noted that 403 of 752 collected acorns had evidence of insect damage at the time of collection, and an additional 33 developed emergence holes while in a greenhouse. He reported that "... insect larvae did not seem to inhibit or adversely affect germination and growth of 58% of the infested acorns, as those that developed seedlings did not differ visually in vigor or growth from the uninfested acorns." Filbertworms were the major insect species involved (433 acorns) followed by filbert weevil larvae (3 acorns).

2. Avian Mortality Sources

Zimmerman (1984) noted that "the ultimate effect of vertebrate animals on acorn availability will be mediated by their dual role as acorn predators and acorn dispersers." This is pointedly true in California with two birds in particular, scrub jays and acorn woodpeckers, acting as both predators and dispersers of acorns. Griffin (1980) measured the removal of valley oak acorns by scrub jays and determined that removal rates exceeded 400 acorns per hour. He did note that "... the numerous acorns which are not found and eaten later are effectively 'planted'" (p. 242). Johnson and Adkisson (1986) measured the number of pin oak acorns transported by blue jays in Virginia. In 28 days, about 50 blue jays transported and cached 150,000 acorns, or about 58% of the total acorn crop. They noted that "... the ease with which [blue] jays move about in human-dominated landscapes fosters oak regeneration in old fields, vacant lots, fencerows, and other untended land isolated from seed-bearing oaks" (p. 46).

Verner (1980) listed 30 species of birds in California which utilize acorns as food. He also noted that birds consume acorn insects.

Birds are rarely noted as specific problems in oak planting. In reality, the attention given to solving acorn predation problems from rodents probably is also effective in preventing avian predation.

3. Mammalian Mortality Sources

That mammals are significant predators of acorns is accented by the number of oak planting-related papers that highlight early collection and protection as items critical to the success of a planting program. Johnson and Krinard (1985) pointed out that "acorn collection must not be delayed, as most acorns will be devoured within a few days by animals..." (p. 58). In their two year study of fall food habits of white-tailed deer in southern New Hampshire, Pekins and Mautz (1987) found that red and white oak acorns were the most consumed foods, and acorns alone or with oak leaves represented over half the fall diet.

McElwee (1970) pointed out that destruction of acorns by rodents had also been the chief cause of failure in direct seeding programs in North Carolina. In the eastern United States, rodents are considered the chief obstacle to reproducing oaks from seeded acorns (R. Johnson, 179; Krajicek, 1955) and in parts of Pennsylvania, rodents contribute to destruction of nearly all acorns (Marquis *et al.*, 1976). Rodents reach direct-seeded acorns even through plastic protectors. Adams *et al.* (1987) had more than 5,000 acorns in Madera County depredated, and they assumed the culprit was ground squirrels, although scrub jays, pocket gophers, and other rodents were undoubtedly present.

Large catches of acorns are sometimes buried by squirrels in the Carmel Valley of California. Griffin (1971) found over 200 germinating acorns of coast live oak in one squirrel chamber. However, in the eastern United States, burial of acorns by squirrels is often accompanied by notching of the acorn tip to kill the embryo, thus preventing germination and transfer of stored food reserves out of the acorn (Barnett, 1977).

Barrett (1980) calculated that at least 37 (22%) of California's terrestrial mammals are known to utilize acorns. "Acorn utilization usually approaches 100 percent where deer, pigs, or bear occur" (p. 277). Cattle can also develop a craving for acorns and consume them in large quantities when available (Wagnon, 1960).

In a study in San Diego County, Bowyer and Bleich (1980), observed that "only when [California black oak] acorns germinate within dense patches of squaw bush or snowberry are they not substantially damaged or completely consumed by deer."

In valley oak savannas of the Santa Lucia Mountains of California cattle are important consumers of acorns, but in their absence, deer are the most conspicuous consumers, and in one area deer virtually live under productive oaks while acorns are falling (Griffin, 1976). Griffin (1980) noted that valley oak acorns on the ground in January were rare at the Hastings Natural History Reservation in Monterey County. When cattle and deer were eliminated as potential predators with exclosures, one experimental plot lost 56% of the 233 planted acorns, presumably to pocket gophers (*Thomomys bottae*). Additional studies revealed predation to planted acorns by deer mice (*Peromyscus* spp.) Summarizing his various experiments, Griffin recorded 756 of 933 planted acorns (81%) eaten or carried away by both avian and mammalian predators.

Johnson and Krinard (1985) found that site-prepared forest openings of two acres or more and agricultural fields had much less rodent damage than those planted under a full forest canopy. They worked with oak species native to the Mississippi area, predominantly Nuttall, Shumard, cherrybark, and water oak. They reported that "squirrels and chipmunks" were the greatest deterrent to direct seeding. Knudsen (1987) concluded that house mice (*Mus musculus*) and California voles (*Microtus californicus*) were the primary small-rodent predators on planted valley oak acorns in his Sutter County study area.

In contrast to squirrels in the eastern U.S. that prefer forest environments and can be discouraged through vegetation management, ground squirrels (*Spermophilus beechyi*) in California are found in open areas and avoid dense woody vegetation (Clark, 1986). Ground squirrels are suspected of causing major losses in artificial oak regeneration studies on oak-grassland range in California (Adams, *et al.*, 1987).

C. SEEDLING MORTALITY SOURCES

1. Insect Mortality Sources

Williams and Hanks (1976) reported that "insects damage hardwood seedlings in various ways: leafeaters strip the foliage, aphids or scale insects drain leaves and stems of sap causing wilt or abnormal growth, and grubs damage the root system..." A detailed review of insect damage to oak trees in southern California was written by Brown and Eads (1965). Koehler (1987) described a variety of insect pests and noted symptoms and signs of their presence.

Brown (1980) noted that over 125 insect species have been recorded as feeding on various parts of oak trees in California. For the most part, these insects affect saplings and mature trees; however, seedlings may also be impacted. Sucking insects include whiteflies, aphids, leafhoppers, tree-hoppers, and scale insects. Sucking insects may inject a toxic saliva into a plant which may kill the plant or cause it to develop deformed. Oak pit scales (*Asterolecanium minus*) have a single generation annually with a peak hatch in May in California. They are especially harmful because of their high reproductive potential and their toxic salivary secretions. Other sucking insects include the crown whitefly (*Aleuroplatus coronatus*), oak treehoppers (Homoptera: Membracidae), the gelatinous whitefly (*Aleuroplatus gelatinosus*), the Standiford's whitefly (*Tetraleurodes stanfordi*), the wooly oak aphid (*Stegophylla quercicola*), the black-punctured kermes (*Kermes nigropunctatus*), the oak wax scale (*Cerococcus quercus*), the Ehrhorn's oak scale (*Mycetococcus ehrhorni*), the oak lecanium scale (*Lecanium quercitronis*), the oak scale (*Quernaspis quercus*), and the coast live oak erineum mite (*Aceria mackiei*).

Leaf-consuming insects defoliate seedlings. The California oak moth (*Phryganidia californica*), according to Brown (1980), is the most important insect pest of oak trees during years of normal rainfall. Populations are extremely variable year-to-year. There are two to three generations each year in California, and larvae are present and feeding from mid-March to mid-September. The larval form, not the adult, consumes oak foliage. Tent caterpillars (*Malacosoma californicum* and *M. constrictum*) have a single, annual generation with larvae feeding from early to late spring. The fruittree leafroller (*Archips argyrospilus*) is a regular defoliator of California black oak in the San Bernardino Mountains. The larvae are most active from late March into May. Other leaf-consuming insects include the live oak leaf cutter (*Vespina quercivora*), the oak ribbed case maker (*Bucculatrix albertiella*), the oak leaf blotch miner (*Lithoclletis agrifoliella*), the stenomid oak leaf tier (*Setiostoma fernaldells*), the phycitid oak leaf tier (*Rhodophaea caliginella*), the western tussock moth (*Hemerocampa vetusta*), the salt-marsh caterpillar (*Estigmene acrea*), the black oak woollybear (*Hemihyalea edwardsii*), the live oak weevil (*Deporaus glastinus*) and the oak leaf sawfly (*Periclista* spp.)

Boring insect damage cuts the xylem and phloem tubes of a plant, resulting in tissue necrosis (Brown, 1980). He noted that water-stressed trees were often most attractive to boring insects. Boring insects affecting oak trees in California included the western sycamore borer (*Synanthedon resplendens*), the oak twig girdler (*Agrilus angelicus*), dry-wood termites (*Kalotermes* spp.), the carpenterworm (*Prionoxystus robiniae*), the Pacific flatheaded borer (*Chrysobothris mali*), the nautical borer (*Xylotrechus nauticus*), the roundheaded oak twig borer (*Styloxus fulleri*), and oak bark beetles (*Pseudopityophthorus* spp.). Griffin (1980) noted damage to planted valley oak seedlings by Pacific flatheaded borers through stem girdling.

In California, grasshoppers (Orthoptera: Acrididae) have been reported as significant predators on young seedlings. Adams *et al.* (1987) reported severe grasshopper depredation on blue oak seedlings in Yuba County, with only three percent of the emerged seedlings surviving as compared to 30% for protected seedlings. Similar protection in Mendocino County resulted in increased survival from 42 to 67%. Griffin (1971) reported the foliage of oak seedlings was often eaten by grasshoppers and cutworms, though the seedlings were not killed. Schmidt (pers. comm.) measured grasshopper damage to natural blue oak seedlings in Mendocino County. Although 40% of the seedlings were damaged, only 4% failed to resprout the following year. Damage consisted of chewing, girdling, or clipping off the stems.

Based on insect damage to 1,500 northern red oak seedlings planted in an upland oak forest in southern Missouri, Kearby (1979) concluded that insects causing bud, leaf, and root losses are potential threats to seedling survival in oak plantings. Bud loss and defoliation were attributed to microleps, May beetles (*Phyllophaga* spp.), click beetles (*Limoneus* spp.), the leafcutting weevil (*Attelebus bipustulatus*, and the Asiatic oak weevil (*Cyrtepistomus castaneus*), the larvae of which feed on oak roots and severely reduces numbers of fine roots. The twig pruner (*Elaphidionoides villosus*) also contributed to seedling mortality.

Linit *et al.* (1986) studied the interactions of insects and planted northern red oak seedlings in Missouri. They collected insects representing 25 families from six orders from the seedlings. Twig gridlers (*Elaphidionoides villosus* and *Aneflormorpha subpubescens*) were associated with seedling mortality. Linit *et al*. noted that the *Elaphidionoides* larvae bored downward in the shoot to within 10 cm of the root collar, and that dead seedlings usually occurred in groups of two to four. These seedlings had been planted in clear-cut plots. The *Aneflormorpha* larvae were found only in plots which had been partially cleared, with damage resulting from larval boring within the shoot. They noted a series of small holes along one side of the shoot through which frass was cast. Grasshoppers were observed feeding on seedlings in clear-cut plots. Linit et al. measured leaf surface area and found that, at the end of the year's growing season, leaf area losses averaged about 22% of the potential standing leaf area. The impact of this defoliation on future growth and survival was not measured. They noted that other researchers had found that late season defoliation was associated with reduced growth of northern red oak seedlings the next spring. However, a loss of 25% or less may have little effect on subsequent growth, and they speculated that a partial defoliation may actually increase the photosynthetic efficiency of the remaining leaves.

Galford (1986b) found that the weevil *Barypeithes pellucidus* fed on all parts of northern red oak seedlings. This is an introduced species known to attack strawberries in Europe. Gibson (1964) did not find any of the acorn-infesting weevils of the genus *Conotrachelus* in the acorns of any native California oak, although this is an abundant acorn pest throughout the eastern United States.

Stem gall insects such as the woody twig gall (*Callirhytis perdens*) have been reported to damage seedlings of coast live and interior live oaks, where they girdle twigs and "...ruin many young trees" (Schettler and Smith, 1980).

2. Avian Mortality Sources

Damage to oak seedlings by birds is not a common occurrence. Verner (1980) listed 110 breeding bird species associated with oak habitats in California. None were reported to consume seedlings, although he noted that band-tailed pigeons (*Columba fasciata*) had been reported to consume new leaf buds, and pine siskins (*Carduelis pinus*) have been reported to consume "foliage." Black-headed grosbeaks (*Pheucticus melanocephalus*) eat oak catkins. However, Verner noted that 35 species of birds eat foliage insects, and 11 species of birds consume bark or wood insects. Knudsen (1987) reported scrub jays pulling on valley oak seedlings on two occasions.

3. Mammalian Mortality Sources

Browsing of seedlings by deer in California is an important factor limiting successful oak regeneration. White (1966) found that 88% of 154 blue oak seedlings marked with stakes were browsed by deer. These had the appearance of small bushes as a result of repeated browsing. He concluded, that since the forbs and annual grasses dry up by July, the green leaves of oak seedlings must become choice browse for deer during the summer. Hannah (1987) noted that eastern oaks (in general) have the ability to persist despite browsing, because of their sprouting potential, but that sprouts may be even more desirable (as deer browse) than unbrowsed seedlings. He stated that current-year shoot growth on oaks was highly preferred by deer, and that rabbits also browsed twigs and stems. Hannah speculated that high deer populations were "...one of the principal hindrances to revegetation of the preferred hardwoods including oaks" (p. 98). He added that even when oaks are at low densities and well mixed with other species, they experience "intense" browse pressure because of the preference deer and rabbits have for oaks. Barrett (1980) noted that voles, pocket gophers, and deer all forage on the leaves and twigs of oaks, "... especially young seedlings." Bowyer and Bleich (1980) found that California black oak seedlings in San Diego County, measured at a density of 6 per hectare in the spring, disappeared in early July in areas of heavy mule deer use.

Griffin (1980) pointed out that browsing by brush rabbits (*Sylvilagus bachmani*) contributed to the deaths of many valley oak seedlings in some of his plots. In one plot, after five seasons, five heavily browsed valley oak seedlings remained out of 320 planted, the tallest 7 cm. He noted that seedling supply seldom exceeds the capacity of rodent predators to eat them. At the Hastings Reservation, pocket gophers were identified as the major rodent mortality source. Griggs (1987) reported Engelmann oak seedlings up to 40 cm high were being killed by pocket gophers, but admitted that this was a rare event.

Alfano (1980) observed five-gallon container canyon live oak seedlings planted on a 10-acre site in Los Padres Forest, and reported that the roots "... provided succulent dinners for hundreds of ground squirrels in the area." In future plantings, roots were covered with a one-inch wire mesh (dimensions unknown). [In this particular case, if the roots were indeed damaged, the culprit was probably pocket gophers, not ground squirrels.]

Rossi (1980) reviewed literature on the impact of livestock on oak regeneration. Barrett (1980) noted that "the browsing domestic livestock and deer may be the most significant factor inhibiting the regeneration of oaks on California rangelands..." Duncan and Clawson (1980) concluded that "there is no doubt that consumption of acorns by domestic livestock... reduces the number of acorns that might possibly become trees." Griggs (1987) recommended that managing cattle in Riverside County oak woodlands through timing of grazing was the most obvious means of influencing the survival of Engelmann oak seedlings, since his observations indicated that cattle were not seeking out the seedlings as food as much as eating them because they were mixed in with the grasses.

The lack of blue oak seedlings and young trees in Kern County was partially attributed to livestock browsing (Twisselman, 1967). At the Hopland Field Station in Mendocino County, Longhurst *et al.* (1979) reported that sheep and deer were responsible for limiting oak recruitment. Franco (1976) surveyed blue oak, valley oak, and coast live oak seedling recruitment on adjacent grazed and ungrazed (since 1960) areas at Stanford University and concluded that the much lower number of seedlings found on the grazed area was the result of livestock grazing. In a southern California study, most seedlings of coast live oak produced from planted acorns survived with cattle exclusion, but all were destroyed where cattle grazing was permitted (Snow, 1973).

While surveying oak regeneration in California, however, Muick and Bartolome (1987) determined that no significant relationship between livestock grazing and oak regeneration emerged. Martin (1987) summarized the impact of large vertebrates on hardwood regeneration. He noted that trees can be affected by consumption of seeds and by trampling and browsing seedlings, but that trampling may also provide a textured microclimate and the physical planting of seeds. McClaran (1987b) also evaluated the relationship between livestock and oak regeneration. Several authors had proposed that livestock browsing, acorn consumption, and trampling limit oak recruitment, while others suggested that livestock grazing favored successful recruitment of blue oak through a grazing regime which reduced herbaceous competition and lowered fire frequencies. McClaran sampled ungrazed, lightly grazed, and moderately grazed sites in Tulare County for blue oak regeneration. Age structure was negatively correlated with grazing (ungrazed plots were older than lightly grazed plots, and lightly grazed plots were older than moderately grazed plots). Seedling density was highest on lightly grazed plots. He concluded that no single event could assure recruitment and any number of factors could limit recruitment, and that successful blue oak establishment was more complicated than presence or absence of livestock. Near the University of California Hasting Reservation in the Santa Lucia Mountains, blue oak stands ungrazed by livestock since 1937 possessed no more seedlings than stands on neighboring ranches where grazing was continuous (White, 1966). In this study, deer browsing was identified as a factor limiting growth of many oak seedlings.

D. ACORN PROTECTION

1. Protection From Insects

Bonner and Vozzo (1987) listed two methods for treating acorns to kill weevil larvae. One method was the immersion of acorns in hot water (120° F) for 40 minutes. The second was fumigation with methyl bromide, carbon disulfide, or thiamine bisulfate. Both techniques are potentially hazardous to the acorn, however. They recommended the safest alternative was avoiding treatment through proper selection, floating, and storage of acorns. Since larvae will continue to emerge, even in cold storage, moving acorns back and forth from cold (2-5° F) to room temperature several times will encourage emergence and thus reduce total damage to the embryo and cotyledon. For acorn insects, Brown (1980) noted that while insecticides and fumigants are possible, acorns held in cold storage would retard the development of the insects.

Dorsey (1967) attempted to use systemic insecticides to control *Curculio* spp. on white and red oaks in West Virginia. Results were mixed, with some treatments increasing the production of non-weeviled acorns while acorn viability decreased. Results were inconsistent from year-to-year. In general, chemically-treated trees had more dried-up acorns than the untreated ones. Bidrin and phorate produced more sound and fewer weeviled acorns.

Crocker *et al.* (1987) looked at the possibility of using microwave radiation to selectively control *Curculio* spp. larvae in viable acorns. Microwave radiation affected mortality of both the larvae *and* the acorns; quenching the acorns in water after treatment reduced injury to the acorns and, unfortunately, the larvae. They indicated that this technique did not seem promising as a means of *Curculio* control.

Schettler and Smith (1980) proposed maintaining high quality acorn crops by spraying seed trees in the wild as needed to prevent infestations from California oak moths and filbert weevils.

2. Protection From Birds

Williams and Hanks (1976) suggested hardware cloth screens as protection from seed-eating birds in nursery environments.

3. Protection From Mammals

Johnson and Krinard (1985) noted that no suitable repellent was available for squirrels and chipmunks for use during direct seeding of acorns. Williams and Hanks (1976) recommended hardware cloth (no size specified) as protection against seed pilfering by moles, chipmunks, and squirrels. McElwee (1970) pointed out that repellents, screens, and other protective measures had proven necessary in some instances and not in others, "... depending upon the size and tenacity of the rodent population" (p. 23). Tappeiner and McDonald (1980) recommended "... pinned-down cone screens..." to protect planted California black oak acorns "...from rodents, especially squirrels" (p. 109). They noted that protection from pocket gophers, deer, and cattle would aid in seedling establishment. Knudsen (1987) reported that a 1.3 cm galvanized hardware cloth, buried 1 m in the ground [extension above ground unknown distance] was hypothesized to have prevented rabbit and small rodent damage to valley oak acorns and seedlings.

Bush and Thompson (1989) described in detail the "collar and screen" technique for protecting oak tree acorns (and seedlings). They have planted thousands of oak trees with good success. The technique involves wrapping a piece of aluminum screening around a plastic, bottomless container (like a one quart cottage cheese container without a bottom). The acorn or seedling is planted inside the container, then the screen is wrapped around the top edge of the container, where it is attached with a piece of wire.

Seedling of Nuttal oak acorns in forest openings greater than 100 ft. on a side reduced rodent damage (Johnson and Krinard, 1987). The acorns used in these Mississippi studies were sown soon after collection, and this practice may impart an advantage; the investigators theorized that, compared to stored acorns, newly collected acorns do not exude odors attractive to rodents. Of acorns sown, they suggest that 35% should be able to establish seedlings in commercial plantings. Earlier work reported by Johnson and Krinard (1985) identified forest openings 2 acres or larger in size are necessary to reduce loss of acorns to rodents.

E. SEEDLING PROTECTION

1. Protection From Insects

Brown (1980) questioned the cost-effectiveness of wildland oak insect pest control, stating "... oaks in a wild, forest situation will probably have a much lower unit value, and cannot justify very costly pest control action" (p. 192). He recommended initially working to improve the vigor of a infested tree (and presumably a seedling). Insecticides are the primary alternative for sucking insects. Leaf-consuming insects may require insecticides, but a number of natural enemies of these insects may also be affected. *Bacillus thuringiensis* is effective against the California oak moth. Carbaryl and acephate have also been recommended for controlling the larvae of oak moths (Koehler, 1982). For boring insects, Brown recommended tree invigoration as a first line of defense.

Schettler and Smith (1980) recommended Orthene, Cygon, or Metasystox for extended control of aphids and whiteflies in the nursery. For a quick reduction, they recommended Diazinon, Malathion, Sevin, or other short-residual surface insecticides. For oak moth larvae, recommendations included Orthene, Lindane, and *Bacillus thuringiensis*. Stem gall insects such as the woody twig gall would be most effectively controlled in a nursery environment with an enclosure made of a fine mesh shade cloth.

Milstead *et al.* (1987) listed natural enemies of the California oak moth (oakworm). There are a number of pathogens, predators, and parasites which attack the egg, larvae, pupa, and adult stages of the oak moth.

A current list of management options for controlling a number of oak consuming insects was prepared by Koehler (1987).

2. Protection from Birds

Since avian damage to seedlings is rare, protective strategies for preventing bird damage have not been developed. Caging to keep out rodents probably serves as a barrier for birds also.

3. Protection from Mammals

Williams and Hanks (1976) recommended that a 10 foot high fence might be necessary to prevent white-tailed deer damage to oaks in nurseries (and presumably out-plantings). They noted that rabbits could be excluded with a 6 foot high fence with a 1-2 inch mesh, or they could be trapped or shot. Pocket gophers (presumably *Geomys* spp.) could be trapped or killed with poison bait, and they noted that controls were most effective during the spring and fall when gophers were most active. Finally, they reported that "mice" could be trapped or poisoned.

Utilizing rigid mesh plastic protectors, Adams *et al.* (1987) increased survival of valley and blue oak seedlings from 1/3 to 13 times that without protection. At these locations, they identified problem animals as jackrabbits, cottontail rabbits, squirrels, and pocket gophers. They noted that the rigid mesh plastic protectors were not effective against pocket gophers.

Pancheco (1987) reviewed the success of two valley oak planting operations in the Santa Monica Mountains National recreation Area. They initially used an aboveground protective cage made of 1 inch poultry wire, plus an underground "pocket" made of 1/2 inch aviary mesh. The upper cage was held in place with a heavy gauge wire formed in a "U" shape. This procedure seemed to work well for small browsers, but cattle readily pushed the screens over and damaged the seedlings. The second planting operation used a similar screen except that the upper cage was extended downward so it could be buried an inch or so below the surface or held down with rocks. Cattle were not present at this site. Pancheo noted that damage from browsers to both sites was high, and that many of the surviving seedlings had multiple stems. Many of the caging techniques listed above for protecting acorns from predation are also effective for protecting seedlings.

General references on controlling damage from rodents and larger browsing animals to oaks, agricultural crops, and structures include Timm (1983) and Clark (1986a,b). Most articles on animal damage management in California can be found in the 13 volumes of the *Proceedings of the Vertebrate Pest Conference*. Although none of these articles are written explicitly for oak regeneration, many of the animal management tools have applicability to protection of acorns and seedlings from mammals and birds.

F. CONCLUSIONS

This review makes it clear that any serious revegetation program for oaks must incorporate planning, resources, and commitment to preventing animal damage to planted acorns and seedlings. In many situations this input must persist beyond the first one or two years. There are a number of areas that this review found data lacking, however. These include:

- *comparative efficacy of alternative screening mechanisms*
- *data on the cost-effectiveness of damage prevention programs*
- *accurate and specific indentification of insect, bird, or mammal involved in damage*
- *specific details of damage mechanisms*
- *species-specific responses to varying degrees of damage from different agents*
- *benefits of insects, birds, and mammals in reducing competition, and through their planting activities*

In addition, there were numerous unsubstantiated claims of protection without adequate controls, and identification of damage vectors based on presence at a site, not on actual observation or experimental manipulation. In short, although we can recognize that damage factors must be considered, the level of sophistication in understanding damage processes and in refining damage control systems is low.

RESEARCH STUDIES

STUDY 1. THE EFFECT OF ACORN SIZE ON BLUE OAK SEEDLING GROWTH
Lead Investigator: Doug McCreary

INTRODUCTION

The starting point for any program of artificial regeneration of native oaks in California is the collection, handling and storage of acorns. For most oak species the volume of acorn crops differs tremendously from year to year. Since white oak acorns cannot be successfully stored for more than a few months, during "heavy" production years, many more acorns are available than can be used. This offers the opportunity to improve regeneration success by only outplanting those acorns that have the best chance for high survival and vigorous growth.

Some have suggested that acorn size may influence field performance. According to this theory, large acorns may have an advantage since they have more food stored in their cotyledons, providing greater energy for initial root growth. The ability to rapidly grow a deeper, more developed root system may allow seedlings to maintain a more favorable moisture status during the first year because they can tap deeper soil horizons where greater moisture is available. This ability could be very important in the dry Mediterranean-like climate of California and could make the difference between surviving and dying, especially during dry years.

Some research relating acorn size to performance has been conducted, but there have been conflicting results. In an early study, Korstian (1927) reported "unmistakable advantage in total germination and survival in favor of large acorns" for four eastern oak species. He also found an increase in overall seedling size related to initial acorn size during the first growing season. McComb (1934) found a close correlation between size of acorns and a variety of seedling characteristics for chestnut oaks, while Matsuda and McBride (1986) reported a positive relationship between acorn size and total seedling size and weight. In a study with *Quercus Ilex*, however, Aissa (1983) reported that germination was not dependent on acorn size or weight. Bonner (1988) reviewed several studies that cautioned that size advantage may not persist and that genetic factors may be more important than seed size.

The following study was initiated to determine if the size of blue oak acorns is related to germination, survival, or growth.

METHODS

The study consisted of two parts, both conducted at the University of California Sierra Foothill Range Field Station (elevation 200 m), 30 km northeast of Marysville. Part 1 was an outplanting of 720 acorns in a field plot fenced to exclude deer and cattle. Part 2 was a growth box study of planted acorns which allowed periodic harvest and measurement of seedlings.

In late September, 1988, approximately 1,000 acorns were collected from each of three trees near Bangor, California, a location 25 km from the field plot and of similar elevation. The acorns were either hand picked directly from the branches or knocked off the trees with long poles and picked up from tarps paced underneath. The average size of acorns varied according to the tree they were picked from. Tree 1 had acorns that were predominantly small; Tree 2 had predominantly medium-sized acorns; and Tree 3 had large acorns. Representative samples determined the range of acorn fresh weights for each tree collection, and each was sorted into three size classes. The ranges and size classes selected are shown in table 1. Acorns were soaked for 24 hours, air dried, and then stored in plastic ziplock bags at 0-4° C. Prior to soaking, samples of six acorns were taken from each of the size classes to determine moisture content by weighing before and after oven drying. Moisture content of each acorn size class was consistent within the single tree collections regardless of tree source. Trees 1, 2, and 3 differed, however, with moisture contents of 41.9 percent, 47.3 percent, and 50.4 percent, respectively. There were also apparent differences in ripeness as indicated by ease of picking from the different source trees.

Prior to planting, some acorns in every size class began to germinate in cold storage, and these were separated out. The remaining ungerminated acorns were placed on moist vermiculite in germination boxes at lab room temperature of 15-23° C. Once germinated, as defined by an emerging radicle .5 cm or longer, they were returned to the cooler with those previously germinated until planting.

Field Trial

The field plot was on a northeast facing 15 percent slope, in Sobrante-Las Posas, very rocky loam. Competing vegetation had been glyphosate treated in early fall and the dead plant cover and top few centimeters of soil carefully scalped off by tractor blade. A uniform planting area was thus created, with 720 planting spots arranged in eight blocks of nine rows each, a randomized complete block design. Each row had 10 planting spots on 30-cm centers; the rows were 60 cm apart. Rows were randomly assigned to acorns from the nine different tree source-acorn size classes. Acorns were planted over a 3 week period beginning December 20, 1988. All but 80 acorns were planted in the first week; 40 from Tree 1 and 40 from Tree 3 were slower to germinate in the germination boxes and were planted two weeks later than the rest. All were planted on their sides at 2-3 cm depth with radicles pointing in natural downward position. Only acorns with radicles less than 2 cm were planted.

Beginning in March and continuing throughout the summer the plot was evaluated twice weekly for seedling emergence, which was defined as first visible sign of the shoot. The plot was hand weeded on occasion, but competing vegetation was very slow to return. No irrigation was provided. Year-end survival and height measurements were taken, and the plot was similarly monitored the following year.

Growth Box

A selection of acorns from Tree 2, the medium sized acorn tree, was reserved for planting in two plywood growth boxes. Each box measured 50 cm by 90 cm by 100 cm deep. The boxes were each partitioned into ten compartments 8 cm wide using polyethylene covered sliding partitions. Each compartment was filled with soil from the field plot site, sifted through a 1.3 cm screen, and compacted by thoroughly watering to promote settling. The planting design was a split plot, so that each removable compartment contained four replications of randomly assigned small, medium, or large pre-germinated acorns. All acorns were planted on December 19, 1988, with points up and then covered with 2-3 cm soil. This planting position was necessary to fit in all the acorns, with 2-3 cm spaces between them. It differed from the on-side position of our field plantings. Extra acorns were planted on outside planting spots to serve as buffers and were not included in the data. The outermost compartments, which corresponded to the first and last harvest dates, were also considered buffers. The boxes were kept out of doors except for a brief period (two nights) of sub-freezing temperatures when they were moved to an unheated warehouse.

It was possible to harvest the acorns in each compartment by removing the entire compartment and either carefully excavating the acorn and its root system (early stages only), or gently removing all soil with a fine water spray. Roots were thus recovered in very clean condition, nearly 100 percent intact. We measured and calculated acorn fresh weight prior to planting, dry weight to fresh weight ratio at harvest (an index of nutrient depletion), total length of root system, number of branched roots vs. tap root configuration, dry weight of root in 20 cm segments, numbers of laterals emanating from the first segment, length of longest lateral, length and weight of shoot, and date of shoot emergence. The first compartment was harvested one month after planting. So little growth had occurred that the next harvest occurred one month later on February 21, 1989, and every two weeks thereafter until June 13.

Data were analyzed by ANOVA and, when significant differences ($P \leq .05$) were detected,by a Fisher's Protected LSD test. Harvest dates were treated as random variables, but by necessity the compartments had to be harvested in a serial, non-random fashion. We believe this not to have been a serious violation of the design since the differences measured between harvest dates were in all cases very great.

RESULTS

Field Trial

In the field, the timing of acorn emergence was unusual. Generally, the emergence pattern was not typical of our experience for this site. The main emergence period was April 1 - June 1 (fig. 1.1). Fast germinating species like blue oak typically show emergence curves considerably steeper in slope and much earlier in the year after late fall planting (McCreary 1990b). Furthermore, the 64 percent emergence for the first year was somewhat low, although not unusually low from the experience of others for this site. Unusual weather patterns could account for these results. We would have expected greatest emergence during February - March. During these two months, the Field Station recorded minimum temperatures for several days as low as -10 and -5° C; and February's mean low was 1.7° C, compared to the 20 year norm of 5° C. Precipitation in March 1989 was in excess of 30 cm, compared to the norm of 9 cm. McClaran (1987a) observed poor emergence under wetter conditions, and Matsuda and McBride (1989) noted delayed shoot development associated with decreasing temperatures of higher elevations. What was noteworthy in our study was a very delayed emergence of 14 percent of the acorns. Four percent of the acorns emerged in the fall after an unseasonably wet September. The following spring and summer 10 percent (70 acorns) more emerged for the first time, bringing our total plot emergence to 74 percent. We are not aware of reports of such extensive delayed emergence in the literature.

Table 1.2 summarizes results for different sized acorns, disregarding parent tree. For 1989, significantly more seedlings from the largest acorns emerged. A greater proportion of these seedlings also survived than did those from the smallest acorn size class. While the largest acorns also had the highest percent survival in 1990, the differences were not statistically significant. Larger acorns also produced taller seedlings, and this relationship lasted into the second year of growth, with an increasing magnitude of height difference between large-acorn seedlings and small-acorn seedlings. The incremental growth differences from 1989-90, while greatest for the largest acorns, were not significant at the $P \leq .05$ level.

Table 1.3 summarizes our data for acorn size differences in relation to their parent trees. While there are trends toward increasing emergence, survival, and height depending on parent tree, the significance of these differences do not present a clear pattern, and there were no significant differences between the parent trees with regard to shoot emergence date or seedling height. Since large acorn size was found to make a difference in emergence and survival, we expected to observe significant differences between the small acorn tree and the large acorn tree, because the small acorn tree's acorns weighed 1.0-5.0 gms, while the large acorn tree's weighed 4.0-9.5 gms. This was not the case. While the large acorn tree tended to have greater emergence, survival, and height growth, the only significant patterns for parent tree were for survival in 1990 (table 1.3). The 1990 survival analysis also showed a tree by acorn size interaction that complicates the parent tree significance for this variable. But when we examined the parent tree by acorn size class combinations, we found that the large acorn tree in all cases had the highest survival. We would, thus, still accept parent tree effect as significant for survival.

Acorns which emerged for the first time in the second year were distributed throughout the plot in a spotty fashion. There were too many missing values for whole rows to do a valid ANOVA analysis. However, table 1.4 summarizes our findings for this interesting phenomena. There seems to be a trend for greater year-end height related to acorn size. Parent tree seems also to be important, as seen in table 1.5, with the large acorn tree producing most of the new emergers.

Growth Box

Table 1.6 summarizes the result of our analysis. The most interesting finding was that total root weight was significantly related to acorn size. The average weights of roots from large acorns were almost double those of the small acorns. This relationship was also true for the first 20 cm root segment, which merely indicates that this was where most of the root mass was located. Over the course of this study, 72 percent of the total root weight was, on average, accounted for by this root segment. Root weights, regardless of acorn size, increased in a somewhat similar manner over time (fig. 1.2), the differences in magnitude increasing, especially after the tenth week when most above ground shoot growth commenced. Root lengths, on the other hand (fig. 1.3), were very similar for all acorn sizes and increased at a similar rate. There were no significant differences for average root lengths.

A similar pattern was observed for shoot weight and shoot length; large and medium sized acorns produced significantly heavier shoots than did small acorns, while shoot lengths were not significantly different.

There were no significant differences between acorn size classes as regards the length of the lateral root zone or the number of laterals in the first root segment. However, the subjective impression that large acorn roots were "bushier" was supported by the significant difference between the longest laterals of the large and small acorns.

When we consider the index of depletion of the acorn's cotyledon reserves as measured by the ratio of acorn dry weight at harvest over initial fresh weight (fig. 1.4), it is clear that these reserves are utilized similarly over time independent of acorn size. There were no significant differences and ratios were almost identical.

DISCUSSION

The data indicate that acorn size in blue oaks is significantly related to initial seedling growth. The field trial demonstrated that larger acorns convey an advantage to seedlings which is reflected especially in the ability to produce taller seedlings. Larger acorns also produced heavier and more developed root systems in the box trial. It was somewhat surprising that root length was not affected by acorn size in our growth box. We had initially reasoned that larger acorn size would be advantageous since larger acorns could rapidly grow deeper root systems, thus accessing soil moisture unavailable at shallower depths. The simulated field conditions of our box data did not support this hypothesis. However, the growth box limited our investigation to depths <100 cm, and differences might have been detected had we been able to track root growth for a longer period to greater depths. Still, the greater mass and branching of root systems produced by larger acorns would seem to promote uptake of both moisture and nutrients and account for the greater seedling heights observed.

The growth box component of this study was intended to shed light on the below ground development which might be occurring in the field plots. We did not expect such rapid root growth. When the last compartment was harvested on June 13, roots had already reached beyond the one meter depth of our box. Most of this growth began after January 19. Extensive root development preceded shoot emergence, and we were unable to obtain shoot growth comparable to that in our field plot because our seedlings outgrew the box depth, terminating observation. Root growth was not affected by the low temperatures we experienced, which was to be expected from the findings of Matsuda and McBride (1987). Average root lengths for February and March,1989 (fig. 1.3), for instance, when air temperatures were especially low, increased in roughly the same manner as for periods when temperatures were much higher.

The average emergence date for the box can only be considered an estimate since compartments were destructively harvested over time and any acorn that hadn't emerged by harvest date was therefore not recorded for emergence. However, if we consider the last six harvest dates, where emergence was nearly complete in all compartments, average emergence date was April 1. This compares to April 20 for the field plot. Twenty-nine out of a total 144 acorns in these last six harvest compartments failed to emerge but were still alive. Of these non-emergers, 59 percent had a multi-branched root system rather than a normal tap root system, compared to 24 percent occurrence of such root systems among those which emerged. Multi-branched systems result from damage to the radicle early in development and can be artificially induced by simulated injury (Carpenter and Guard 1954, unpublished data). It is therefore probable that the delayed emergence observed in both box and field plot was related to early radicle injury.

It would appear that the root system serves an important storage function as a reserve for seedling resprouting. Blue oak seedlings readily resprout (Griffin 1971) and have an enormous potential to remain alive for long periods without photosynthetic support or other above ground functions. After complete stem clipping of seedlings, for example, an entire year may pass before above ground functions resume (Welker and Menke, in press). This could be seen as an adaptation to herbivory, fire, and xeric or other harsh environmental conditions. Our results indicate that this ability is established before the seedling ever receives any photosynthetic support. The rapid translocation of nutrients to below ground storage in blue oaks may even give an acorn a two-growing season potential for successful shoot emergence under favorable environmental conditions as we observed in our field plot. Large acorn size would logically be an advantage in this regard, and while we have indications that this might be the case, we cannot say with certainty that acorn size provides a significant advantage for such delayed emergence or resprouting. The potential for delayed emergence of acorns also suggests caution in interpreting survival or emergence results from a one-year study.

The large volume of the first 20 cm segment of our seedling root systems in the growth box, coupled with its significant relationship to acorn size for all harvest dates of our box study, point to this root segment as the principal storage region or recipient of translocated nutrients from the acorn. The segment resides in the most competitive part of the soil profile, has the least amount of active root growth, and the most suberization, and would appear to be most favorably situated for a more passive storage function.

CONCLUSIONS

The results of these trials suggest that increased growth and survival may be obtained by selecting acorns from trees that produce large acorns, as well as by selecting the largest acorns within single tree collections. Large acorns tended to produce taller seedlings with roots of greater mass. However, there was considerable variation in field performance between the three trees tested. For the medium acorn tree, greater acorn size resulted in a clear pattern of increased survival. For the other two trees, however, there was relatively little difference between acorn size classes. This suggests that the benefits in artificial regeneration of selecting larger acorns within single tree collections could vary greatly depending upon the parent tree. In general, the height gains from increased acorn size, while not great in the first year, do show significant persistence. Only further tracking of our field plot will reveal how persistent these advantages may be, and at this time, based on the limited evidence, we would not recommend selecting large acorns as a regeneration prescription. However, researchers should be aware of possible acorn size effect when conducting comparisons of seedlings to ascertain various treatment effects on planted acorns.

Finally, it should be noted that other considerations may influence decisions concerning which acorns to select for planting. Even if larger acorns are deemed superior from a growth and survival standpoint, smaller acorns may be preferred to meet other objectives, such as the use of local seed sources and maintaining adequate genetic diversity by planting acorns from a large number of parents.

Table 1.1 -- Ranges in acorn fresh weight (gm) for each tree-size combination

Parent Tree	.... Acorn Size / Class .... Small	Medium	Large	Average Weight
Tree 1, Small Acorn Tree	1.00 - 2.50	2.51 - 3.50	3.51 - 5.00	2.9
Tree 2, Medium Acorn Tree	2.00 - 3.50	3.51 - 4.50	4.51 - 6.00	4.0
Tree 3, Large Acorn Tree	4.00 - 6.00	6.01 - 7.50	7.51 - 9.50	6.8

Table 1.2 -- Field plot averages for different sized acorns, regardless of parent tree - 1989-90[1]

Acorn Sizes	pct Emergence 1989	pct Year End .... Survival.... 1989	1990	Year End .. Height (cm).. 1989	1990[2]	Average Emergence Date (1989)
Small	59^{a}	57^{a}	67	5.2^{a}	19.3^{a}	May 4
Medium	63^{ab}	62^{ab}	68	5.1^{a}	17.4^{a}	May 8
Large	71^{b}	70^{b}	76	7.1^{b}	24.5^{b}	May 5

[1] Values for each variable (columns) are not significantly different ($P \leq 0.05$), Fisher's LSD test, if they are followed by the same letter or none.
[2] Data for this variable tracks those seedlings emerged in 1989 only.

Table 1.3 -- Field plot averages of all acorn size classes from different parent trees[1]

Parent Tree	pct Emergence 1989	pct Year End .... Survival.... 1989	1990	Year End Height (cm) 1989	1990[2]	Average Emergence Date (1989)
Small Acorn tree	67^{a}	65^{ab}	70^{a}	5.2	17.9	May 4
Medium Acorn tree	57^{b}	55^{a}	61^{b}	5.6	20.8	May 5
Large Acorn tree	70^{a}	69^{b}	80^{c}	6.5	22.5	May 9

[1] Values for each variable (columns) are not significantly different ($P \leq 0.05$), Fisher's LSD test, if they are followed by the same letter or none.
[2] Data for this variable tracks those seedlings emerged in 1989 only.

Table 1.4 -- Averages of acorns newly emerged in second year by size class[1]

Acorn Sizes	Number Emerged	pct Vacant spots w/New Emergers	Emergence Date	Year End Height
Small	29	29	April 20	3.4
Medium	22	25	April 14	6.0
Large	19	28	April 12	6.4

[1] Values for each variable (columns) are not significantly different ($P \leq 0.05$), Fisher's LSD test, if they are followed by the same letter or none.

Table 1.5 -- Averages of acorns newly emerged in second year by parent tree[1]

Parent Tree	Number Emerged	pct Vacant spots w/New Emergers	Emergence Date	Year end Height
Small Acorn tree	21	26	April 12	4.6
Medium Acorn Tree	16	15	April 16	5.1
Large Acorn Tree	33	46	April 18	6.1

[1] Values for each variable are not significantly different ($P \leq 0.05$), Fisher's LSD test, if they are followed by the same letter or none.

Table 1.6 -- Averages for variables measured in growth box trial for 8 harvest dates[1]

Variable	Acorn Size		
	Small	Medium	Large
Total Root Weight (g)	.278[a]	.376[b]	.498[c]
First 20 cm segment of root (g)	.203[a]	.268[b]	.359[c]
Root Length (cm)	47.5	49.6	51.2
Shoot Weight (g)	.119[a]	.184[b]	.196[b]
Shoot Length (cm)	5.09	6.61	6.43
Length of Lateral Root Zone (cm)	56.0	57.2	59.3
No. of Laterals >1 cm in 1st Root Sgmt	38.9	44.8	50.3
Length of Longest Lateral (cm)	6.8[a]	8.7[ab]	11.3[c]
Acorn Fresh Weight (g)	2.98[a]	3.94[b]	5.09[c]
Acorn Dry Weight (g)	1.03[a]	1.36[b]	1.81[c]
Ratio Dry Weight/Fresh Weight	.35	.35	.36

[1] Values for each variable are not significantly different ($P \leq 0.05$), Fisher's LSD test, if they are followed by the same letter or none.

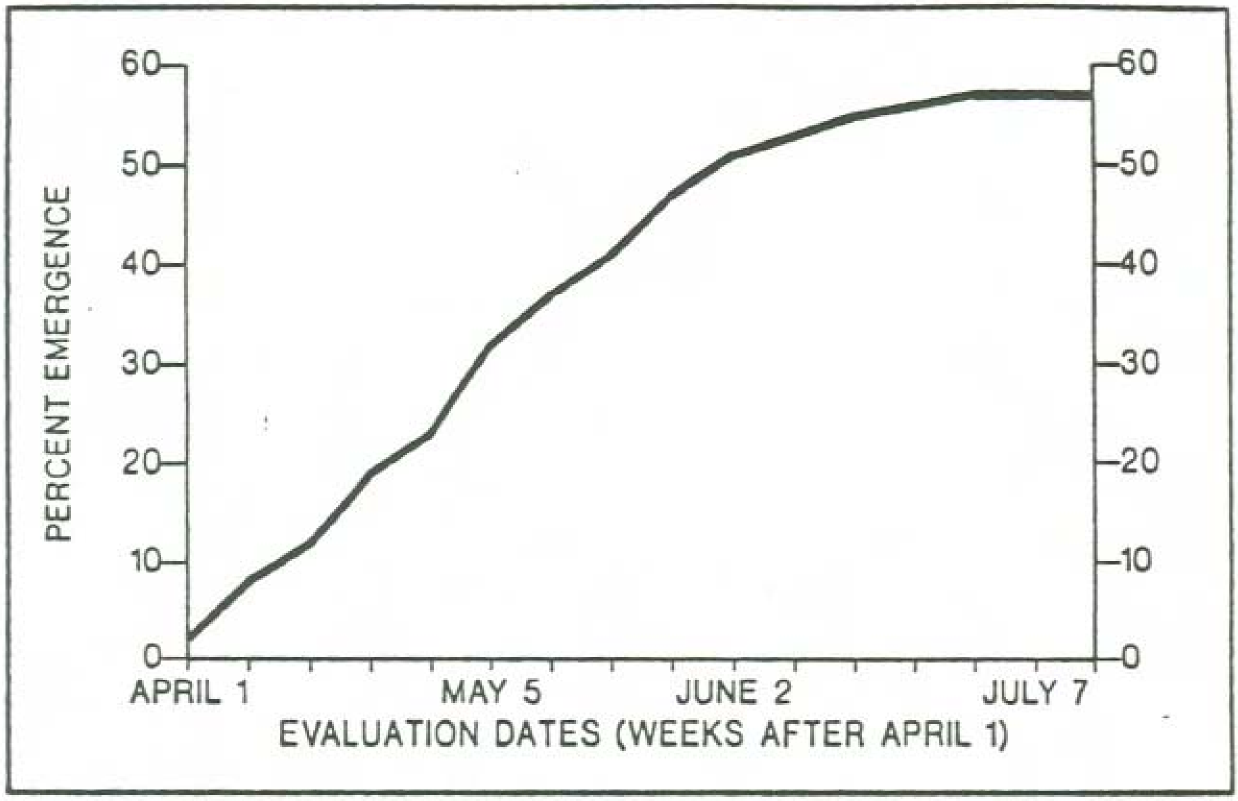


Figure 1.1—Cumulative emergence of field planted acorns in 1989.

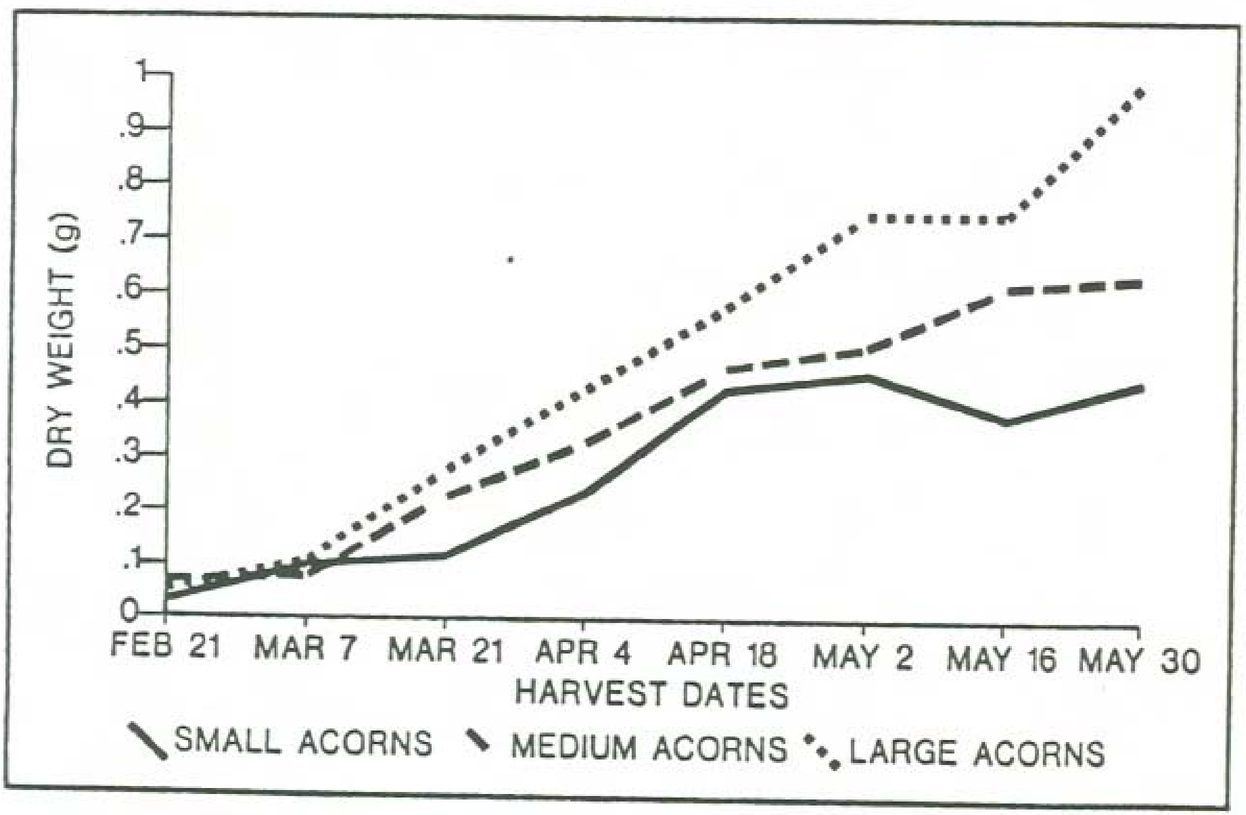


Figure 1.2—Averageroot weights for 3 sizes of acorns harvested on different dates.

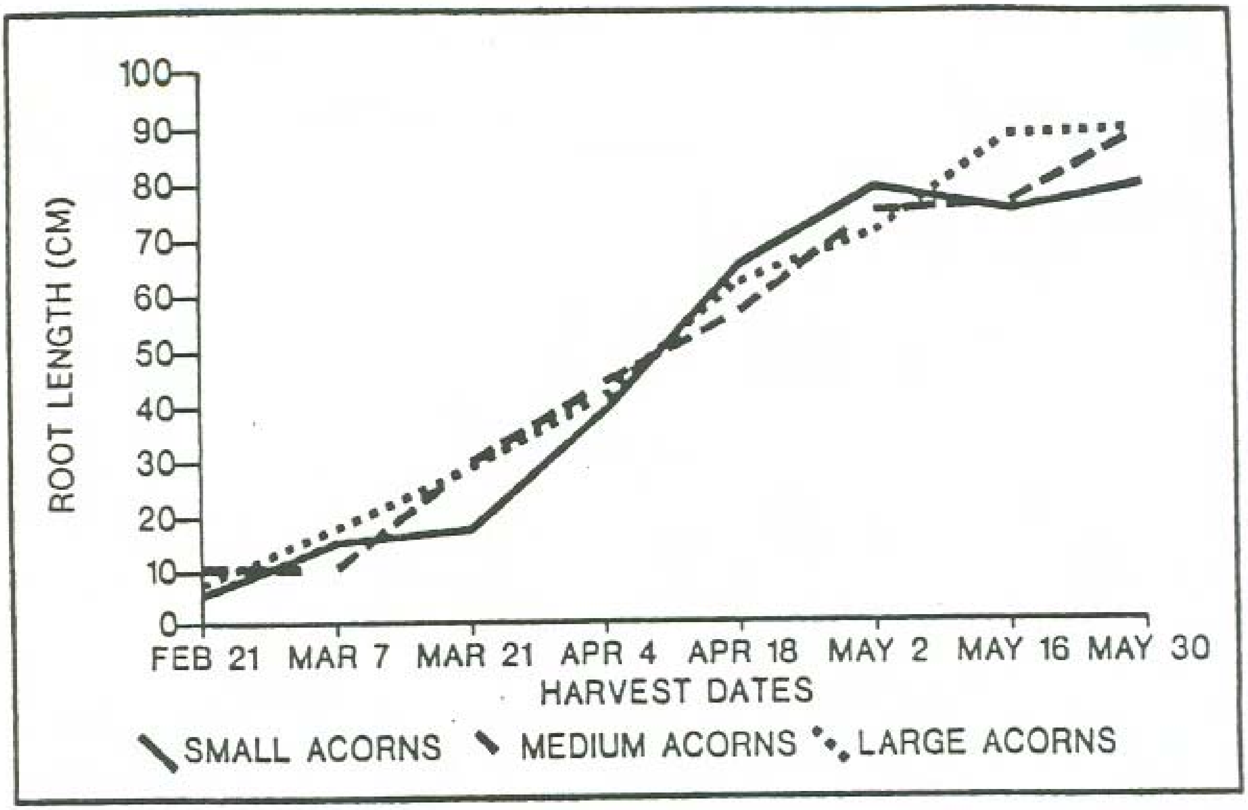


Figure 1.3—Averager root lengths for 3 sizes of acorns harvested on different

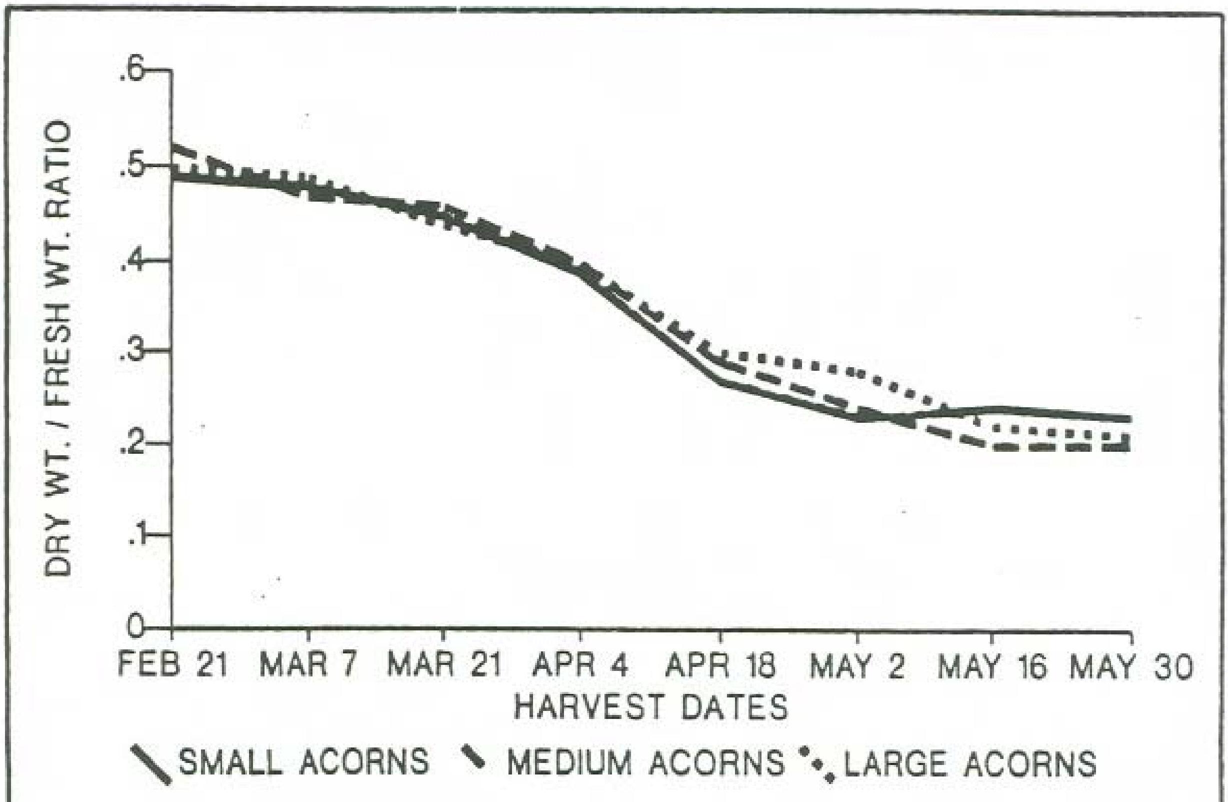


Figure 1.4—Average acorn dry weight/ Fresh weight ratio for 3 sizes of acorns harvested on different dates.

2. EFFECT OF PLANTING DEPTH ON DEPREDATION, EMERGENCE, AND SURVIVAL OF VALLEY AND BLUE OAK ACORNS

Lead Investigator: William Tietje

INTRODUCTION

Poor natural regeneration of several of California's native oaks has increasingly been recognized. Blue and valley oak are not regenerating sufficiently to maintain current stand densities. Factors that contribute to the regeneration problem include conversions of oak woodlands to urban and agriculture lands, increased fuelwood cutting, and competition from introduced Mediterranean annual grasses.

Artificial regeneration is an important option available for replacement of lost oaks. Although successful oak regeneration techniques have recently been developed (Griffin, 1971; Russell 1971; Wright and others 1985; Johnson and Krinard 1985; Johnson and others 1986; Vande Linde 1987; McCreary 1989c), animal depredation of direct-planted acorns is a common problem. Studies have examined several methods to reduce animal depredation. Johnson and Krinard (1985) concluded that a large-sized clearing around the planting site minimized animal damage. Russell (1971) believes that effective repellents would be a cost-efficient animal deterrent which needs to be developed. Cages surrounding planting sites work to keep animals out (Adams and others 1987), but are also expensive to install.

Acorns planted at or just under the surface are more likely to be depredated than acorns planted at deeper depths (Russell 1971; Griffin 1971; Johnson and Krinard 1985; Borchert and others 1989). Optimal planting depth, however, has not been determined, at least not for California oaks. This paper reports on the response in terms of animal depredation, seedling emergence, survival, and growth to valley and blue oak acorn planting depth and number of acorns planted per planting site.

STUDY AREA

The study site was established on the Santa Margarita Ranch in east-central San Luis Obispo County about 23 km northeast of San Luis Obispo. The climate of the area is Mediterranean, characterized by warm, dry summers and cool, wet winters. Average annual monthly temperatures range from 8° C in January to 23° C in July. Average annual rainfall totals about 53 cm. Typically, no rain falls during May to October.

Topography of the area is gently rolling to hilly. Residual soils, formed in place on sedimentary or secondary rocks, predominate. The dominant vegetation community is foothill oak woodland (Barbour and Major 1977). Dominant tree species in the oak woodlands include blue and scrub oak on xeric sites and coast live oak and valley oak on the more mesic sites. Gray pine (*Pinus sabiniana*) is frequently interspersed with the oaks. A variety of brush, forbs, and annual grasses occupy the oak woodland floors and grassy openings.

Since European settlement of coastal central California, the predominant land use of the Santa Margarita Ranch has been livestock production. Currently, the ranch is moderately stocked with cattle. All data were collected on the ranch during January to October 1989 within a 1.8-m tall welded-wire fence exclosure constructed around 0.6 ha of grazed pastureland. Forbs, predominantly filaree (*Erodium* spp.), and annual grasses covered the exclosure; no trees or brush occurred within the exclosure.

METHODS

Acorn Collection and Storage

In October 1988, valley and blue oak acorns were collected from trees on the Santa Margarita Ranch. The fungicide Captan was applied to the valley oak acorns, but not to the blue oak. All acorns were then refrigerated at 2° C until planting.

Site Preparation

In January 1989 in the 0.6-ha exclosure, 960 planting sites were laid out in a 2.4- by 2.4-m (8- by 8-foot) grid divided into four replicates of 240 planting sites each (randomized complete block design). The large distance between planting sites was used to reduce the likelihood that a potential acorn depredator which, if it happened to find one planting site, would find another. Twelve treatments were assigned randomly to each replication using the following variables: blue oak or valley oak; planting depths of 1.3, 5.1, or 10.2 cm (0.5, 2.0, or 4.0 in, respectively); and one or three seeds per planting site.

Each planting site was permanently marked with an aluminum identification tag wired to a steel rebar stake. In all replications, treatments were randomly assigned in groups of five planting sites. During 2-11 January 1989, acorns were planted the same compass direction and distance from the steel stakes by use of a template in the shape of an equilateral triangle with 10.2-cm sides. For one-acorn sites, an acorn was planted at the top angle and at each angle at three-acorn sites.

Two tools were used to plant the acorns at the proper depth. Whenever possible, a 2.5-cm diameter soil-sampling tube, marked with depth gradations (1.3, 5.1, and 10.2 cm) was used. At unusually rocky planting sites, holes were dug with a 3.8-cm diameter soil auger. The augered holes were measured with a ruler to ensure proper depth for planting. Soil removed with the soil-sampling tube or auger was replaced and firmed against the seed.

To minimize competition from grasses and forbs, herbicides were applied to the site twice: 1.1 kg atrazine and 0.7 kg oxyfluorfen per ha on 14 and 15 February and 1.1 kg glyphosate per ha on 10 March. A backpack spray pump was used to make 1.5-m swaths centered on each row.

Site Monitoring

On-site rainfall was measured with a Taylor rain gage. Rainfall data was taken after each storm from January to May. Rainfall data for the same months was obtained from the U.S. Weather Bureau, Salinas Dam Weather Station (3 km east of the study site). Average annual rainfall for the study site was obtained from the U.S. Weather Bureau, Paso Robles, California (33 km north of the site).

Two soil samples were taken from the site in March and analyzed by the Soil Science Department, California Polytechnic State University, San Luis Obispo. The two locations for the tests were determined ocularly to represent the extremes in soil that occurred.

In order to determine the kinds of animals present on the site, live trapping and observational animal scans (Fagerstone, 1984) were conducted during March and April. Trapping sites were laid out on a 11- x 11-meter grid. There were 49 trap sites consisting of forty 7.6-cm and nine 12.7-cm Sherman live traps. Trapping was done twice: 8-9 and 21-23 March.

During 15 March to 3 April, a total of 17 10-minute periods of observation were made with a pair of field binoculars from a vehicle parked along a blacktop road about 20 m from the exclosure. Number of animals seen on and around the 0.6-ha study plot was recorded. Animal sign and species occurrence were not documented prior to study start up and planting, but cursory observations did not indicate any appreciable differences from during the study.

Oak Monitoring

Above-ground depredation was monitored twice a week during January to March. Acorn depredation was determined by examining each planting site for digging and other signs of animal activity such as acorn shell remains. Suspected depredation was confirmed ocularly at 1.3-cm planting sites and by examining manually the digging for acorns planted 5.1 cm deep. Since the 10.2-cm depth was too deep for these methods, a ruler was inserted into the hole to measure the depth of digging and to feel for an acorn.

Seedling emergence data was collected weekly from the time the first seedling emerged in March and until emergence of the last seedling in July. Seedlings were located by ocular examination of each planting site. Upon emergence, each seedling was protected from animal damage with a 13-cm diameter aluminum-screen cage pinned to the ground.

Seedling survival and growth data were recorded in October 1989. Survival was determined ocularly. Each seedling was placed in one of two categories: alive or dead. All leaves had to be completely brown for the seedling to be dead. Seedling height was measured (nearest cm) from ground level to the tip of the terminal bud. One outside row (32 planting sites) was omitted from the analysis of height data because of heavier herbicide application.

Fate of Acorns Not Emerged

Since acorns could have been depredated from underground, a sample of acorns that did not appear to be depredated, but did not produce a seedling, was dug up to determine their fate. In December 1989, 20 planting sites in each of the four replications (118 acorns) were selected for sampling. Each site was dug to the proper planting depth with a shovel and the soil sifted to help ensure finding the acorns, if present.

Data Analysis

For analysis of animal depredation, three-seed planting sites were considered depredated only when all three acorns were gone. For seedling emergence analysis, only one seedling had to come up at a site for it to be successful. If more than one seedling emerged at a three-seed site, the tallest living seedling in October 1989 was used to assess seedling survival and height. This approach seemed reasonable at three-seed sites because a practical application of planting multiple acorns is to increase the chance that one vigorous seedling is produced.

General trends of the data were determined using Macintosh EXCEL. Macintosh STATVIEW II (Feldman and others 1987) was used to perform ANOVA to test the treatment effects on percent depredation, emergence, and survival. A multiple factor factorial, non-repeated measures, balanced model (Winer 1971) was used to compute the ANOVA table shown below.

ANOVA

Source	Degrees of Freedom
Planting Depth	2
Species	1
Number of Seeds	1
Planting Depth by Species	2
Planting Depth by No. of Seeds	2
Species by No. of Seeds	1
Planting Depth by Species by No. of Seeds	2
Blocks	3
Error	33
Total	47

If there were significant interactions among any of the treatments (species, planting depth, and number of acorns per planting site) for any variable (acorn depredation; seedling emergence, survival, and height), the table interaction means was examined to determine the cause of the interaction and how it may affect interpretation of the significant main effects. For each variable, a Duncan's multiple range test (Steel and Torrie, 1960) for the main effects was conducted to determine which treatment means were significantly different at the $P \leq 0.05$ level. Since seedling height data had an unequal number of observations, Student's *t*-tests were used to test the significance of seedling height differences for each of the three treatments.

In Table 2.1, rainfall is compared between 1988 and the year of the study, 1989. Table 2.2 shows the means of the variables (acorn depredation; seedling emergence, survival, and growth) for the treatments (acorn species, planting depth, and number of acorns per planting site). Figure 2.1 illustrates the differences in means of acorn depredation and seedling emergence variables for the species, acorn depth, and number of acorns per planting site treatments.

RESULTS

Site Monitoring

The year 1989 was dry for San Luis Obispo County (U.S. Weather Bureau, Sacramento, California). At the Salinas Dam Weather Station only 26 cm of rainfall were recorded compared to an average annual rainfall of 53 cm. During the first five months of 1989, 14.6 cm of rain fell on the study plot compared to 24.3 cm recorded at the Salinas Dam Weather Station during the same months in 1988 (table 2.1).

Since the results of the two soil tests were similar, they are averaged here. The soil texture was a sandy loam comprised of 75 pct sand, 12 pct silt, and 13 pct clay. It held only 24 pct water at saturation. The pH was 6.2. Organic matter (nitrogen: 89 kg per ha) was more than average for the soils of the area and, due probably to the residual from grazing, the phosphorus was very high (69 ppm dry weight). Potassium, calcium, and magnesium (123, 623, and 41 ppm dry weight, respectively) were all low due to leaching of the sandy soils and because the soils had low ability to retain nutrients.

In March 1989, during the first trapping period, 28 deer mice (*Peromyscus maniculatus*) were caught in Sherman live traps (98 trap nights) and nine during the second period of trapping (147 trap nights). No other animals were captured. Fresh California ground squirrel (*Spermophilus beecheyi*) digging was common after March within and around the study plot. The fact that ground squirrels were not trapped in any of the 12.7-cm Sherman live traps may be due to trap design: the live traps had aluminum rather than woven-wire sides. Ground squirrels are relatively wary of entering the aluminum traps (R. Schmidt, pers. comm.).

California ground squirrels were observed during the 17 10-minute observational scans: three times on the study site and 32 times on the surrounding area. No other potential mammal acorn depredators were sighted within or around the study plot. Potential avian depredators were not seen on the site. Although periodic checks were made during January to October 1989, pocket gopher (*Thomomys* spp.) mounds were observed only on the area outside the study plot.

Oak Monitoring

There were significant differences for the variables of acorn depredation, seedling emergence, survival, and height for most levels of the three treatments (oak species, depth the acorns were planted, and the number of acorns planted per planting site) of this study. There were also significant species by planting-depth interactions; valley oak and blue oak did not respond (in terms of acorn depredation, seedling emergence, and survival) in the same way to the depth the acorns were planted. Each variable is explained below.

Acorn Depredation.--Of the 960 planting sites, nearly half (43 pct) were depredated. Valley oak acorns were depredated significantly more (61 pct) than blue oak (25 pct).

Depredation was also much different among planting depths, ranging between 100 pct at one-seed sites for valley oak planted 1.3 cm deep to 0 pct at three-seed sites for blue oak planted 5.1 cm deep. Depredation of valley oak acorns decreased from 93 pct at 1.3-cm planting depth to 29 pct at 10.2 cm; with one and three-acorn sites combined, these differences were significant. In contrast, blue oak depredation decreased significantly from 60 pct at the 1.3-cm depth to 9 pct at 5.1 cm, but did not change significantly between the 5.1 and the 10.2-cm (6 pct) depths. The fact that animal depredation of valley oak decreased about equally between planting depths but blue oak did not, resulted in significant oak species by planting depth interaction. Finally, for blue oak and valley oak acorns planted at 1.3 and 5.1 cm, depredation was significantly less at three- than one-acorn planting sites. This difference did not occur at the 10.2 cm planting depth where depredation was nearly equal.

Depredation of acorns began within about a week of planting and continued until mid-March, when emergence of non-depredated acorns began. Occasional depredation of acorns occurred until the end of July. At most planting sites that were depredated, a small hole about 3 cm diameter was dug, apparently by deer mice, to the depth the acorn was planted. A much greater amount of digging at other depredated planting sites suggested the acorns were taken by ground squirrels. There was no evidence of digging at planting sites by any other kind of animal.

Seedling Emergence.--Valley and blue oak seedlings emerged from mid-March to the end of June. A seedling came up at 23 pct of the 960 planting sites. Seedlings grew at significantly more blue (35 pct) than valley oak (12 pct) planting sites.

Few valley oak seedlings emerged (4 pct) at the 1.3-cm sites. At the 5.1- and 10.2-cm planting sites, about equal proportions emerged (16 pct and 17 pct, respectively). On the other hand, for blue oak, the most (49 pct) seedlings emerged at the 5.1 cm; significantly fewer (21 pct) emerged at 10.2 cm depth. This between-species difference in seedling emergence accounts for the significant species by planting depth interaction - the lowest seedling emergence for valley oak was at 1.3 cm planting depth but at 10.2 cm for blue oak. Finally, one-acorn sites produced significantly fewer seedlings than three-acorn sites: 5 pct vs. 18 pct and 23 pct vs. 47 pct for valley oak and blue oak, respectively.

Seedling Survival.--Nearly all the blue oak and valley oak seedlings that emerged in spring 1989 (a seedling at 23 pct of the 960 planting sites) were still alive the following

October (a seedling at 20 pct of the planting sites) when the last data on seedling survival were taken. Therefore, results of the ANOVA for seedling survival are nearly identical to those for seedling emergence: the same differences on survival were detected between species, acorn planting depth, and numbers of acorns planted per planting site. Also similar to the emergence results, there was a significant species by planting depth interaction for seedling survival.

Seedling Height.--The average height of all seedlings in October at the end of their first growing season was 7.0 cm. Valley oak seedlings were significantly taller than blue oak seedlings (8.3 cm and 6.5 cm, respectively) but, importantly, average heights of valley and blue oak seedlings from acorns planted at 1.3-, 5.1-, and 10.2-cm depths were about the same (9.0, 8.2, and 8.3 cm tall, respectively, for valley oak; 6.8, 6.7, and 5.8 cm tall, respectively, for blue oak). Finally, average seedling height was greater at three-- compared to one-acorn planting sites (9.2 and 5.2 cm tall for valley oak; 6.8 and 5.8 cm tall for blue oak); the difference was significant for valley oak.

Fate of Acorns not Emerged

In December 1989, we searched for 118 acorns (80 planting sites) that had apparently not been depredated nor produced a seedling. Of these, 70 pct had produced both a root and a sprout, but the sprout did not reach the surface of the ground, and 12 pct appeared inviable. The fate of the remaining 18 pct, which were not found, could not be determined, but there was no evidence of animal depredation.

DISCUSSION

Planting Depth: 1.3 vs. 5.1 vs. 10.2 cm

Acorns planted at 1.3 cm were more easily detected by deer mice and ground squirrels present in the study plot than those planted deeper (5.1 or 10.2 cm). Observational scans and live trapping on the study plot indicated these surface-feeding rodents were quite common. The acorns planted just below the soil surface were especially susceptible to depredation from above ground. But, even if the acorns had not been depredated, other studies (Griffin 1971; Russell 1971; Johnson and Krinard 1985) indicate they might not have germinated due to adverse soil conditions near the surface: temperatures average higher and evaporation of soil moisture occurs at a faster rate. In this study, these conditions were compounded by the low rainfall and the sandy soils with low water-holding capacity.

On the other hand, the deeper-planted acorns, especially those planted 10.2 cm, were depredated the least because they were less easily detected by smell and the small rodents present on the study plot generally do not dig deep to get acorns (Russell 1971; Johnson and Krinard 1985; Borchert and others 1989). Had gophers been active in the study site, depredation of the more deeply-planted acorns would have likely been greater (Russell 1971).

It is not completely clear why many of the acorns that germinated at 10.2 cm deep did not come up. The long-term grazing of the study site likely compacted the soil, making soil penetration more difficult. Matsuda and McBride (1987) attributed mortality of germinated blue and valley oak acorns to hard soils that did not allow root penetration.

But, in this study, it seems that compacted soil would have equally impeded seedling emergence of acorns planted at 1.3 and 5.1 cm deep. Especially for blue oak, planting 10.2 cm deep apparently resulted in such a large distance for the shoots to penetrate that many were not successful in emerging from the soil.

Species: Valley Oak vs. Blue Oak

The planting depth by blue oak species interactions in the ANOVA tests indicated that these factors acted together on acorn depredation, seedling emergence and seedling survival. A possible explanation for greater depredation, even at deeper planting depths is, simply, that valley oak acorns are larger. Barnett (1977) did a study with pignut hickory (*Carya glabra*) and white oak in which the hickory was depredated at a higher rate than the oak. Barnett attributed this to the stronger odor of the hickory nut due to its larger size; it was easier than the smaller white oak for predators to locate. Similarly in this study, the larger valley oak acorns may have exuded a stronger odor which attracted predators more, even at the deepest planting depth. It seems unlikely that use of the fungicide Captan on the valley oak, but not on blue oak acorns, increased depredation differentially. According to Sid Sakamoto (pers. comm.), Captan does "not attract small mammals". In fact, for seed-eating birds, Captan has been used as a repellent.

Number of Seeds: One vs. Three

This study confirms the validity of the acorn planting technique: several acorns per spot. Three-seed planting sites had, overall, less acorn depredation and greater seedling emergence, survival, and height. Notably, apparently, 10.2 cm (4 in) was adequate space between seeds to minimize the likelihood of finding all three once one was located--at least for the kinds of animal depredators on the study plot. The higher emergence and survival rates at three-acorn sites indicates that competition between seedlings was not a problem during the first growing season. Greater average height, moreover, of seedlings at three-acorn sites was due, simply, to the opportunity to select the tallest of three seedlings. The advantages of planting multiple acorns are noteworthy because acorns are easy to collect and planting several per planting site is not much more difficult than planting one.

RECOMMENDATIONS

The following management recommendations are suggested:

(1) Plant acorns about 5.1 cm (2 in) deep. This will help reduce animal depredation but will not be too deep for seedlings to come up. Somewhat deeper planting may be better in areas or years of high rainfall and/or soil with good water-holding capacity.

(2) Plant several seeds per planting site, spaced at least 7 cm (several inches) apart.

(3) Plant the species of oak trees which is most suited to the rainfall and soil conditions of the area.

Planting at the recommended depth does not preclude the need to protect the planting site. Planting at the optimal depth may increase the chance of success of protected sites, and may make successful planting more likely when protection of the planting site is not practical.

Table 2.1 Rainfall (cm) recorded at the Salinas Dam Weather Station during January to May 1988 compared to rainfall recorded during the same months in 1989 on the study site.

Month	Year 1988	Year 1989
January	7.2	3.6
February	5.1	4.1
March	4.7	5.3
April	7.1	0.8
May	0.2	0.8

Table 2.2 Average fate of 960 sites planted at three depths: 1.3(0.5 in), 5.1(2 in), or 10.2 cm (4 in), with either one (1) or three (3) valley (V) or blue (B) oak acorns per site during January to October 1989 in the Santa Margarita Ranch study plot, San Luis Obispo County, California

Acorn Planting Dept (cm)	Depredation (%)[d]				Emergence (%)[d]				.. Survival (%)[d] ..				...... Height (cm)			
	V		B		V		B		V		B		V		B	
	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
1.3 (0.5 in.)	100^{a}	86	75^{a}	45	0^{a}	4	23^{a}	51	0^{a}	4	20^{a}	50	0^{a}	8	6^{a}	8
5.1 (2.0 in.)	75^{b}	50	18^{b}	0	9^{a}	23	34^{a}	63	5^{a}	20	25^{a}	55	4^{a}	10	6^{a}	7
10.2 (4.0 in.)	29^{c}	28	6^{b}	6	5^{a}	28	13^{b}	28	5^{a}	25	10^{b}	25	7^{a}	9	5^{a}	6

a,b,c, Pairs of means (averaged over number of seeds) not followed by the same letter within a column are significantly different ($P \leq 0.05$) by Duncan's multiple range of test and for height by Student's *t* test.
d All percentages are based on 960 planting sites.

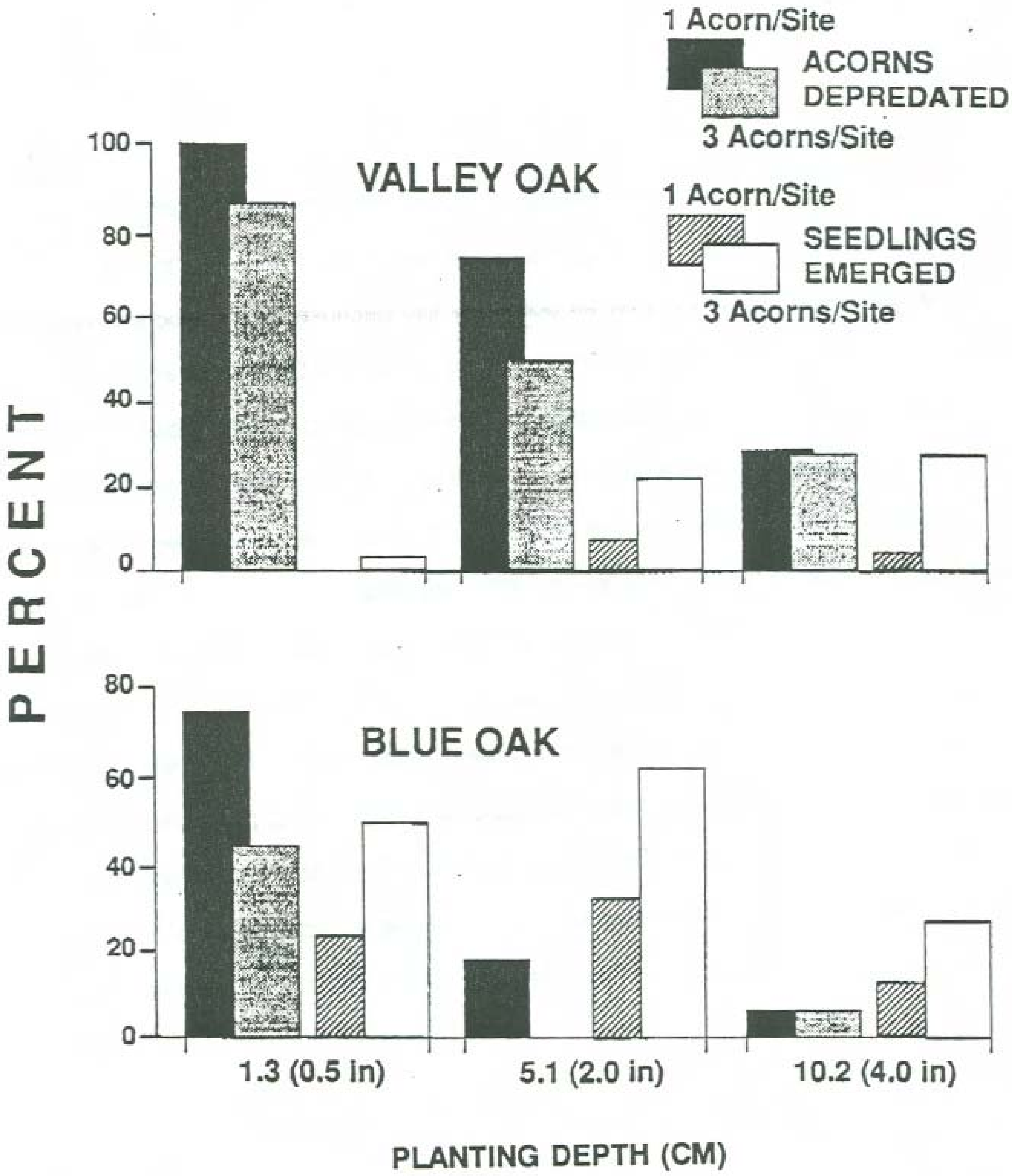


Fig.2.1. Percent valley oak and blue oak acorns depredated and seedlings emerged from tree planting depths (1.3, 5.1, and 10.2 cm) at one- and three-acorn planting sites.

STUDY 3. THE EFFECTIVENESS OF RADICLE TRIMMING, AUGER PLANTING, MYCORRHIZAL INOCULATION, AND IRRIGATION ON ENGELMANN OAKS

Lead Investigator: Tom Scott

INTRODUCTION

Our study examined the effects of radicle trimming, soil augering, mycorrhizal inoculation, and irrigation on Engelmann oak seedlings. We used the South Coast Research and Extension Center as our study site because the climatic conditions are representative of most stands of Engelmann oaks, and the Center has irrigation facilities and 24-hour staffing. Our original plan called for four comparisons involving 50 pairs of seedlings grown from acorns. Because of the short duration of the grant, we chose to use one-year-old seedlings as well as acorns. Furthermore, since emergence rates of Engelmann acorns are typically low (c. 35%), we doubled (104) the number of acorns planted in each trial. Finally, a review of the literature indicated that native soils were better than commercially available inoculum for mycorrhizal infection of roots. Perry et al (1987) suggested that the mix of mycorrhizal species found in native soils was better adapted to local conditions and is often superior to single fungi produced in a different region of the country. We therefore took woodland soils under Engelmann oaks at the Santa Rosa Plateau rather than use commercially available mycorrhizal inoculum, because woodland soils appeared to be a more realistic means of enhancing seedling growth.

METHODS

Study Site

All trials were conducted at the South Coast Research and Extension Center, on the western edge of the Engelmann oak distribution. Although precipitation is lower than in many parts of the species range, temperature and evapotranspiration are similar. We used Field 23, which was used for avocado trees until 1983. This crop received fertilization (21-0-0; 75 lbs/acre/year) and simazine (4 lb. total applied material/acre/year) until 1983. The field was annually planted with barley every summer from 1983 to 1988 to remove the simazine. The field was leveled and irrigation was installed in October 1988. We began on-site planting in November 1988. Each planting site was served with 1 gal/hr emitters and was given approximately 2 hours (c. 2 gals) irrigation per week for the first year. Then beginning in October, 1989, watering was based on California Irrigation Management Information System (CIMIS) data and all sites not in the irrigation experiment received 100% of CIMIS irrigation. (See description of irrigation treatments for more detail.)

We assumed that weed control was essential to restoration success and all treatments received equal amounts of control efforts. Weeds were sprayed with glyphosate (0.5% aqueous concentration) in February 1989, approximately 4 weeks before the first seedlings emerged. Weeds were subsequently controlled by hand trimming around seedlings, and by disking between rows.

Soils

The Soil Conservation Service classified the on-site soils as San Emigdio, a fine sandy loam. Soil depths in the area typically are 60 inches, although soils were over 120 inches at augered sites. Available water capacity ranges from 0.12 to 0.17 in/in, with moderately rapid permeability (2.0 to 6.0 in/hr). Salinity is low (<2 Mmhos/cm); pH is moderately alkaline (7.9 to 8.4) and the soil is slightly calcareous. Soils are fertile and capable of supporting most kinds of agriculture.

Seed Stock

Acorns used in the inoculation and radicle trimming experiments were taken from one Engelmann oak, located at Case Springs, Camp Pendleton Marine Base, San Diego County. We used this oak because: 1) its annual production of acorns is relatively constant, and 2) the acorns it produced had a narrow variance in weight and size. It also occurred in a relatively isolated stand with only four trees as an upwind source of pollen. Seedlings (58) used in the inoculation experiment were also from acorns collected from this tree in 1987. Acorns used in the augering and irrigation experiments were collected from several other trees at Case Springs.

Seedlings used in the augering and irrigation experiments came from acorns gathered from three locations in San Diego County in November 1987: 1) Oak Ridge, near Palomar Mountain (32 seedlings); 2) Deerhorn Valley, near Jamul (33); Portrero Creek, near Tecate (22); and Camp Pendleton (17). These locations were not chosen by design; acorns from these areas produced more seedlings than other areas and were taken by default. Seedlings from each location were equally divided among irrigation treatments or pairs in the augering experiment.

Acorn Handling

Acorns picked off the tree were combined with green acorns collected off the ground; all acorns showing brown colors were discarded. All acorns under 5 gms or over 6.9 gms were discarded; the remaining acorns were placed with peat and vermiculite in burlap bags to germinate on 11 November 1988. We used eight bags, 2 per trial, and placed 250 to 300 acorns per bag. Pre-germinated acorns were planted on 22 and 30 November 1988.

Seedling Handling

Acorns were germinated in peat and vermiculite and then planted into paper pots (5x5x25 cm) and grown in a greenhouse for six months. In April 1988, seedlings were transplanted into 10x10x40 cm tree pots and moved onto the site and covered with shade cloth. Potting soils consisted of standard University of California mix for citrus crops. Transplanting to the field occurred on 22 and 30 November 1988. Seedlings were planted into 15 cm wide by 40 cm deep holes; a posthole-digger was used to insure holes of consistent size and depth. Seedling root ball and soil were removed from pots, lowered into holes and back-filled with the excavated field soils. We did not attempt to disrupt or untangle root masses. Methods for planting seedlings in the mycorrhizal experiments are described in that section.

Measuring Emergence, Growth, Leaf Production, and Mortality

Two acorns were planted at each site to increase the probability of producing a seedling. When two seedlings emerged at one site, we selected the seedling with the greatest height and did not use the second seedling in the experiment (seedlings of equal height were secondarily judged by leaf number). Seedling emergence was recorded when stems or leaves could be detected above the ground surface, not when seedlings began to buckle the soil. In some cases, breaking soil surfaces required two weeks. Seedling heights were measured from soil level to point of the tallest (live) apical meristem. Growth was measured by taking monthly measures of seedling height and comparing changes over time. Die-backs were recorded as a net loss in height. Leaf numbers were counted for all seedlings with less than 100 leaves. Once a seedling reached this leaf number, we classified leaf numbers into six density rankings from category 1 = sparse leaves to category 6 = dense volume of leaves. The number of dead leaves was also changed to a three-rank classification system when seedlings reached 100 leaves: 1 = no dead leaves, 2 = dead leaves present but less than half of total leaf number, and 3 = over half of the leaves were dead. All classifications and 90% of the measurements and counts were made by one observer who did not know which trees were receiving treatments and which were for comparison.

Trimming of Acorn Radicles

Acorns were placed into quadruplet groups of equal radicle length. Two members of each quadruplet had 5 mm of their radicle tips trimmed off, while the other two were left intact. The pair with trimmed radicles were planted 30 cm apart on each side of an irrigation emitter. The comparison pair (with untrimmed radicles) were planted at the next emitter down the irrigation line (1.55 m away). As stated above, we used the first seedling to emerge from each pair and disregarded the second seedling if it emerged. In all, 56 quadruplets were planted at 112 emitters along four irrigation lines.

Augering Holes for Planting Sites

Acorns were sorted and grouped into quadruplets as in the radicle trimming experiment (radicals were not altered). Two members of each quadruplet were planted at a site with a 2.45 m deep hole (15 cm diameter). The other two members of each quadruplet were planted 3.1 m (10 ft) away in unaltered soils. Both treatment and comparison sites were placed on the same irrigation line. Two lines of these sites (28 sites, 14 augering/comparison pairs per line), for a total of 28 pairwise comparisons were planted.

Twenty eight seedlings were paired by height similarities and planted into 14 augering/comparison pairs. One member of each pair was placed into an augered hole, while the remaining member of each pair was planted 3.1 m (10 ft) away in unaltered soils. Both members of each pair were situated along the same irrigation line.

Inoculation of Planting Sites

Acorns were sorted into quadruplets as in the radicle trimming experiment. We collected soils from underneath Engelmann oak woodlands at the Santa Rosa Plateau in western Riverside County. To obtain soils, we brushed aside leaf litter and duff, taking the first 20 cm of soil. Approximately 0.5 liter amounts of this soil (600 gm) was placed into plastic bags (56) and driven to the planting site. Acorns were sorted in quadruplets, placed into treatment and comparison pairs and planted under the same system used in the augering experiment. The treatment sites were excavated to 10 cm (4 in) and the holes were backfilled with soil previously collected under trees. Acorns were placed on top of this soil and covered with soil from the field. The soil at comparison sites was disrupted in the same manner as the treatment sites. However, holes were backfilled with field soils. Treatment and comparison members of each pair were situated on the same irrigation line. A total of 56 quadruplets were planted at 112 emitters along 4 irrigation lines.

Seedlings for the mycorrhizal experiment were taken from seedling stock from a prior experiment. We used seedlings which had not been inoculated with mycorrhizae after a year of exposure to woodland duff (sterilized and untreated). We transplanted the experimental seedlings grown with woodland duff (decomposing leaf litter) and those grown with sterilized (steamed) duff into the field. The seedlings had already been paired by height similarities for the prior experiment and only those pairs closest in height were used in the field experiment. The unsterilized member of each pair was planted with approximately 500 gm of native woodland soil, while the sterile member of the pair was planted with no soil amendments. The native soils were added to the side of the root and soil mass. In most cases the root and soil mass weighted approximately 5 times more (2.5 to 4.5 kg) than the soil amendment. Twenty-eight pairs were planted along 4 irrigation lines.

Irrigation of Acorns and Seedlings

Two-hundred-and twenty-four pair of acorns were randomly assigned to planting sites along eight irrigation lines (28 sites per line). The four different irrigation treatments were interspersed among the 8 lines; two lines per treatment. All lines received the same amounts of irrigation during the winter rainy season (November, 1988 to April 1, 1989), equal to about 2 hours (c. 2 gal) per week. Every fourth irrigation emitter was plugged on 1 April 1989, setting up 7 comparison sites per line, with a total of 56 sites over the 8 lines. We had intended to set up four different levels of watering based on California

Irrigation Management Information System (CIMIS); assigning 60%, 80%, 100%, and 120% of our estimate of oak water use. Water was to be applied to all lines at the same interval but in different amounts (hr x gal/hr), ranging from 15 to 45 minutes a week based on evapotranspiration rates and irrigation treatment. However, miscommunication with field station staff delayed the start of watering treatments until October 1989, past the primary time of growth and water stress. The effects of different levels of irrigation on growth and survivorship have been monitored since October, 1989.

RESULTS

Overall Rates of Emergence

We planted 952 germinated acorns at 476 planting sites. By August of 1989 a total of 409 (43%) of these acorns emerged at 276 (58%) sites (150 sites with one seedling, 126 sites with two seedlings). Acorns in rows 15 and 16 had the highest rates of emergence [42 (75%) and 48 (86%) respectively]; acorns in rows 11 and 12 had the lowest rate of emergence [6 (11%) and 7 (13%) respectively]. There were no other significant row effects (Kruskal-Wallis test, $\underline{P} > 0.20$) among the remaining rows. After 790 days, at least one live seedling was still present at 220 sites (46%).

Trimming Engelmann Oak Acorn Radicles

At the end of 440 days, 34 (61%) seedlings with untrimmed radicles had emerged, but only 7 (12%) of the seedlings with trimmed radicles had emerged. Although almost none of the trimmed acorns produced a seedling, acorns with untrimmed radicles produced seedlings at the rate similar to comparison acorns in the other trials.

At the end of 790 days, 14 (25%) of the sites planted with acorns with untrimmed radicles had seedlings that were still alive, and 4 (7%) of the sites planted with trimmed radicles had seedlings that were still alive. However, seedlings from the trimmed radicle sites were taller than those from the untrimmed radicle sites (mean heights of 21 and 10 cm, respectively), although the small numbers made statistical comparisons somewhat meaningless.

Inoculation of Acorns with Woodland Soils

1. ***Emergence.*** A total of 52 (93%) inoculated and 53 (94%) control sites produced seedlings during the experiment. There was no significant difference in the total numbers or rates of emergence between the inoculated and comparison acorns (Table 3.1).

2. ***Height Gains.*** Acorns at inoculated planting sites grew significantly taller seedlings than acorns planted at comparison sites after the first year (Kolmolgrof-Smirnov contingency test; $\underline{P} < 0.01$, $\underline{n} = 43$, $\underline{m} = 42$). By January of 1991, this difference was even more striking, with the mean height of inoculated seedlings (127 cm) nearly three times that of the comparison seedlings (37 cm) (Student's t-test, $\underline{P} < 0.001$, $\underline{df} = 70$). Inoculated sites produced 14 seedlings (33% of total) that grew over 40 cm during the first 440 days and 27 seedlings (73% of total) that grew over 80 cm after 790 days (Table 3.2).

3. ***Leaf Production.*** Acorns at inoculated planting sites produced seedlings with significantly more leaves than acorns planted at comparison sites after the first year (Kolmolgrof-Smirnov test; $\underline{P} < 0.01$, $\underline{n} = 48$, $\underline{m} = 48$). Twenty-two (46%) of those inoculated exceeded the maximum leaf number recorded among the comparison seedlings, after the first year (Table 3.3). After the second year, 33 (89%) of the inoculated

seedlings, but only 9 (26%) of the comparison seedlings had greater than 100 leaves (the maximum counted).

4. ***Mortality.*** Almost all (19) of seedling mortalities (20) the first year resulted from gopher damage to roots. One inoculated seedling died for unknown reasons but may also have been damaged by gophers. By January 1991, 37 inoculated sites (71% of emerged) and 35 comparison sites (66% of emerged) still had at least one live seedling.

Inoculation of Seedlings with Woodland Soils

1. ***Height Gains.*** Inoculated seedlings grew significantly taller in the first 440 days of the study (Kolmolgrof-Smirnov test; $\underline{P} < 0.05$, $\underline{n} = 30$ pairs). The average growth among inoculates was almost three times the rate among comparison trees (Table 3.4). Inoculated seedlings recovered from transplant shock faster than comparison seedlings. Eleven of the inoculated seedlings failed to grow, while 22 of the comparison seedlings failed to grow. If these stunted seedlings were removed from the sample, the mean height of the inoculated seedlings was 20 cm greater than that of the comparison seedlings (fig 3.1).

By January of 1991 (790 days post-planting), mean height of the inoculated seedlings was nearly twice that of the comparison seedlings (Student's t- test, $\underline{P} \leq 0.001$, $\underline{df} = 60$).

2. ***Leaf Production.*** There were no significant differences between the leaf production ratings of inoculated seedlings and those of comparison sites after the first year but bushiness scores were higher in the treated seedlings after the second year. There were also significantly more dead leaves occurring on the inoculated seedlings

during the winter months (October 1989 through February 1990: measured with a Chi-square test in February; $\underline{P} < 0.025$, $\underline{df} = 2$).

3. ***Mortality.*** No seedlings died during the first year of the experiment. By January of 1991, 2 (7%) of the inoculated seedlings and 4 (13%) of the comparison seedlings had died.

Irrigation of Acorns

1. ***Emergence.*** A significant (Chi-square test; $\underline{P} < 0.01$, $\underline{df} = 2$) difference in seedling emergence occurred between the irrigated and unirrigated seedlings through October, 1989 (Table 3.5). Percent emergence was highest in the 80% treatment after CIMIS irrigation began in October, 1989 (Table 3.6). Acorns which received no water after 1 April 1989 had the lowest percentage of seedlings emerge.

2. ***Height Gains.*** There were no significant differences after the first year in the seedling heights of acorns planted among different irrigation and comparison treatments (Kruskal-Wallis test; $\underline{P} > 0.20$, $\underline{n} = 135$). By the end of the second year, mean height of the seedlings receiving the 60% CIMIS treatment was about half that of the seedlings receiving the 80% or 120% CIMIS treatments, but seedlings receiving no irrigation were about equally as tall as irrigated seedlings overall (Table 3.7).

3. ***Leaf Production.*** There were no significant differences in the number of leaves produced by acorns planted among the irrigation and comparison treatments after the first year (counted in October, Kruskal- Wallis test; $\underline{P} > 0.20$, $\underline{n} = 135$). After the second year, mean leaf numbers of the seedlings receiving the 60% and 120% CIMIS treatments were less than mean leaf numbers of the seedlings receiving 80% and 100% treatments, but unirrigated seedlings did not differ from irrigated seedlings.

4. ***Mortality.*** By February 1990, only one seedling had died after the irrigation was stopped (1 April 1989) at comparison sites; two seedlings had died at sites still under irrigation. Three other seedlings had died at unirrigated sites during the months of October and November 1989, for a total mortality of four (7%).

By January 1991, survival rates (% of sites with seedlings present both in 1990 and 1991) ranged from 86% in the seedlings receiving the 60% CIMIS treatment to 56% in those in the 120% CIMIS treatment (Table 3.6).

Irrigation of Seedlings

1. ***Height Gains.*** Irrigated seedlings grew significantly taller and faster than unirrigated seedlings. Sixteen (20%) irrigated seedlings and 17 (61%) unirrigated seedlings failed to grow during the first 440 days of the study. After 790 days, seedlings receiving the 80% CIMIS treatment were generally taller than seedlings receiving other CIMIS treatments and irrigated seedlings were still taller than unirrigated seedlings (Table 3.8).

2. ***Leaf Production.*** There was no significant difference between the irrigated and unirrigated seedling sample distributions among the leaf number categories after the first year, but by the end of the second year a trend toward larger leaf number categories in the irrigated seedlings became apparent (Table 3.9).

3. ***Mortality.*** Only one seedling in the 100% CIMIS treatment died at any of the irrigated or comparison sites after 790 days.

Augered Planting Sites (Acorns and Seedlings)

1. ***Emergence.*** A total of 12 (86%) of acorns emerged from both the augered and comparison sites.

2. ***Height Gains.*** Augering planting sites did not significantly increase the growth of seedlings planted at 1 year of age. However, acorns planted at augered sites grew significantly more than acorns planted at comparison sites after the first year (Kolmolgrof-Smirnov contingency test; $\underline{P} < 0.05$, $\underline{n} = 12$, $\underline{m} = 12$) (Table 10). Mean heights of augered and comparison seedlings after the second year were 39 and 9 cm, respectively, but this difference was not significant (Kolmogorov-Smirnov contingency test; $P > 0.15$, $\underline{n} = 12$, $\underline{m} = 8$). These differences were primarily due to a number of large seedlings at the augered sites; treatment differences were less noticeable at the smaller size classes, but these "growers" were found only at the augered sites.

3. ***Leaf Production.*** Seedlings planted at augered sites did not produce significantly more leaves than those planted at comparison sites. However, acorns planted at augered sites produced significantly more leaves than acorns planted at comparison sites, but this trend was not significant until after the second year (Kolmogorov-Smirnov contingency test; $\underline{P} < 0.01$, $\underline{n} = 12$, $\underline{m} = 8$ (Table 3.10).

4. ***Mortality.*** Augering planting sites did not increase survival of seedlings or acorns during the first year of the experiment. By January 1991, all planted seedlings were still alive, but only 8 (67% of emerged) of the seedlings from acorns planted at comparison sites were still alive compared to 12 (100% of emerged) still alive at the augered sites.

DISCUSSION

Trimming Engelmann Oak Acorn Radicles

The strongly negative effect of radicle trimming on the Engelmann acorns in this study is unequivocal. We found no net benefit in trimming acorn radicles prior to planting other than an increase in height the second year of those that did emerge. While this technique may provide nurseries with better root growth in containers, trimming radicles in our plots greatly reduced emergence and survival. The negative effect may have been enhanced by the amount of irrigation the seedlings received or the level of pathogens in the soil. We excavated 9 trimmed acorns and found that all had rotted in the soil; eight died without producing a shoot, and one rotted before the shoot broke the surface.

Our conclusions predict that radicle trimming of Engelmann oak acorns may be detrimental in most cases. At minimum, our results suggest that acorns should not have radicles trimmed if they are going into unsterilized conditions (such as field plantings) or if they are going to receive irrigation during warm weather.

Inoculation of Acorns and Seedlings

The treatment group achieved greater average height, higher average leaf number, and a higher percentage of growing seedlings than the comparison group. The treatment did not cause any difference in seedling mortality or seedling emergence.

Root morphology of treated seedlings suggested that they were infected with mycorrhizae. Three seedlings stained in 1990 failed to produce evidence of infection, but a second excavation of three trees in 1991 revealed much greater numbers of infected roots on treated seedlings (2) than on a comparison seedling. Under these circumstances, we can define the benefit of using woodland soils to augment acorn planting sites, but cannot define the specific cause. There are three possible explanations: 1) mycorrhizal infection will not become evident until later in the spring, when temperatures increase (but soils are still moist); 2) the benefit resulted from other biological factors in the woodland soil, such as nitrogen-fixing bacteria or some combination of mites, nematodes, and bacteria; 3) the benefit resulted from the physical properties of the woodland soils, such as nutrients, pH, or soil structure; or 4) systematic bias in treatment of planting sites. Plantings were completely interspersed, and the trees with the highest growth rates were randomly distributed across the plot; therefore, field or systematic effects are unlikely. Because the soils are some of the most fertile in the region, it is unlikely that the woodland soil provided additional nutrients.

Irrigation of Acorns

Irrigation improved the rates of emergence of Engelmann oak acorns, but did not significantly improve the growth rates of emerging seedlings. Furthermore, irrigation increased survivorship only for the lowest treatment level indicating that it is probably unnecessary for survival in weed-free soils.

Irrigation of Seedlings

There were significant differences in the growth rates of irrigated seedlings over unirrigated seedlings; however, there were no differences in survival rates or in the leaf density rating of the two groups. It appears that irrigation can double growth rates of Engelmann oak seedlings, but is unnecessary for the survival of seedlings in weed free soils.

Augered Planting Sites

Augering increased the growth and survivorship of trees planted from acorns at this site. However, our sample sizes were relatively small and the efficacy of this treatment may not be applicable to all sites. However, we would expect the beneficial effect of this treatment to be greatest in hard, compacted soils.

CONCLUSIONS

Assuming weed control as a standard treatment of planting sites, the most cost efficient means of increasing growth in Engelmann oak acorns appears to be soil amendment with woodland soils (Table 8). This treatment did not increase survivorship or emergence in our experiment but might if soils at the planting site were less favorable. It did greatly increase the vigor of transplanted seedlings, as measured by the number of seedlings which grew and the average growth rate.

Radicle trimming, on the other hand, resulted in greatly reduced emergence and survival. This practice is therefore not recommended for Englemann oaks prior to direct seeding, at least under conditions similar to those used in this experiment.

While augering appeared to have relatively little effect on emergence or survival, it did tend to increase growth rate and leaf production, especially during the second year. We would therefore recommend using this treatment where conditions would permit easy application (i.e., flat ground accessible by tractor) and soil conditions would hinder root development if soils were left undisturbed.

Irrigation did not improve acorn emergence or subsequent growth of seedlings. It did, however, increase the growth of planted seedlings and did increase the number of seedlings which grew in the treatment group. The cost of irrigation was greater than the soil amendments; it consisted of irrigation pipe and emitters, the labor costs of installation and maintenance, and the cost of water (calculated at $250/acre foot).

We did not test if irrigation affected the success of the woodland soil augmentation. The beneficial effect of this soil may be dependent on maintaining soil fauna. We will not know for certain if irrigation increased the effect of native soils until we remove irrigation from a portion of the treated trees and analyze the results from wildland experiments.

It appears that if low-cost water is available at restoration sites, the cost of irrigation may be low relative to the gain in growth of planted seedlings. Although the short term benefits are obvious, we do not know the effect of removing watering treatments from seedlings which have been irrigated for long periods of time, but will test this effect over the next four years.

Table 3.1 —Counts of emerging seedlings from mycorrhizal experiment.

	March 89	April 89	May 89	July 89	October 89
Inoculated	1	20	37	44	52
Comparison	0	17	34	45	53

Table 3.2 —Height gains (in cm) of seedlings grown from acorns and inoculated with mineral soils.

Treatment	Height	Distribution of seedlings by height					
	Mean ± (SD)	≤ 10	10<x ≤ 20	20<x ≤ 40	40<x ≤ 80	>80	Total
Feb. 1990							
Inoculated	31.3 ± 23.2	11	8	9	14	0	42
Comparison	12.0 ± 7.6	18	22	3	1	0	43
Jan. 1991							
Inoculated	127 ± 66	2	1	2	5	27	37
Comparison	37 ± 30	12	14	1	1	7	35

Table 3.3 — Leaf production in seedlings grown from acorns and inoculated with mineral soils.

Treatment	Number of leaves	Distribution of seedlings by total number of leaves				
	Mean ± (SD)	≤ 20	20<x ≤ 40	40<x ≤ 100	>100	Total
Sept. 1989						
Inoculated	44 ± 33	10	16	17	5	48
Comparison	22 ± 9	19	29	0	0	48
Sept. 1990						
Inoculated	>100[a]	3	0	0	33	36
Comparison	>42	17	8	6	9	40

[a] Leaf no. on trees with more than 100 leaves were simply counted as 100; actual mean is considerably greater than 100 for inoculated trees and slightly greater than 42 for comparison trees in 1990.

Table 3.4 —Height gains (in cm) by one-year-oldseedlings inoculated with woodland soil

Treatment	Height gained	Distribution of seedlings by height increase						
	Mean ± (SD)	≤10[a]	1<x≤2	2<x≤3	3<x≤4	4<x≤5	>5	Total
Inoculated	48.7 ± 54.1	9	2	3	4	2	10	30
Comparison	16.3 ± 32.8	14	6	2	3	2	3	30

Table 3.5 —Emergence at irrigated and non-irrigated acorn sites[a]

Treatment	Number of sites Planted	Number of emerging acorns by period[b]		
		Nov. 1988 to April 1989	April 1989 to October 1989	First Year Total
non-irrigated	56	--	25 (45%)	27 (48%)[c]
irrigated	178	12 (7%)	94 (53%)	106 (60%)[d]

[a] All sites were irrigated from planting (Nov. 1988) until April 1989, at which time the emitters at every 4th site were plugged.

[b] Percentages represent the proportion of sites planted.

[c] Two seedlings emerged before irrigation was cut off; three seedlings died, so that the actual total was 24 (43%).

[d] Two seedlings died, so that the actual total was 104 (59%).

Table 3.6— The emergence and survivorship of seedlings of acorns in the irrigation experiment (beginning October 1989)

Treatment	No. sites planted	Additional no. emerged Oct 89–Feb 90	Total no. emerged(%)[a] by Feb 1990	No. surviving (%)[b] by January 1991	No. dead (%)[b] by Jan 1991
No irrigation	56	0	27 (48%)[c]	17 (63%)	10 (37%)
60% Est. ETO	42	2 (%)	22 (52%)	19 (86%)	3 (14%)
80% Est. ETO	42	0	31 (74%)	21 (68%)	10 (32%)
100% Est. ETO	42	0	28 (67%)	19 (68%)	9 (32%)
120% Est. ETO	42	0	25 (60%)[d]	14 (56%)	11 (44%)

[a] Percent of sites planted.
[b] Percent of emerged.
[c] Three seedlings died so final total actually equals 24 (43%).
[d] Two seedlings died so final total actually totals 23 (55%).

Table 3.7— Height (in cm) of seedlings grown from acorns at irrigated and unirrigated planting sites.

Irrigation Treatment	Height of seedlings in Feb., 1990	Height of seedlings in Jan., 1991	Increase
	Mean ± (SD)	Mean ± (SD)	(%)[a]
No irrigation	9.9 ± 8.9	22 ± 48	12.1 (122%)
60% Est. ETO	10.7 ± 3.7	9 ± 6	(-1.7)(-16%)
80% Est. ETO	9.8 ± 4.9	20 ± 31	10.2 (104%)
100% Est. ETO	9.3 ± 5.5	19 ± 40	9.7 (104%)
120% Est. ETO	10.5 ± 4.3	13 ± 13	2.7 (26%)

[a] Difference between Feb.1990 and Jan. 1991 means divided by Feb. 1990 mean

Table 3.8—Height (in cm) of seedlings planted as 1-year-olds at irrigated and unirrigated planting sites

Irrigation Treatment	height after one year (measured Feb. 1990)		height after two years (measured Jan. 1991)	
	Mean ± (SD)	Increase[a]	Mean ± (SD)	Increase[b]
No irrigation	22 ± 12	10 (79%)	68 ± 50	45 (203%)
60% Est. ETO	53 ± 29	39 (275%)	118 ± 57	65 (122%)
80% Est. ETO	46 ± 31	32 (246%)	136 ± 62	90 (198%)
100% Est. ETO	42 ± 32	28 (201%)	97 ± 69	55 (130%)
120% Est. ETO	53 ± 35	40 (309%)	112 ± 80	60 (102%)

[a] Difference between Nov. 1988 and Feb. 1990 means, difference divided by Nov. 1988 mean x 100

[b] Difference between Feb. 1990 and Jan. 1991 means, difference divided by Feb. 1990 mean x 100

Table 3.9— The distribution of seedlings planted as 1-year-olds among leaf density categories.

Irrigation Treatment	Leaf density rating						
	One	Two	Three	Four	Five	Six	Total
Oct. 1989							
No irrigation	4	15	5	2	0	0	26
60% Est. ETO	1	13	4	1	0	0	19
80% Est. ETO	2	11	6	0	0	0	19
100% Est. ETO	0	11	8	1	0	0	20
120% Est. ETO	5	9	2	2	0	0	18
Total	12	60	24	6	0	0	102
Oct. 1990							
No irrigation	1	8	12	4	1	0	26
60% Est. ETO	1	2	9	5	0	2	19
80% Est. ETO	0	4	6	6	3	0	19
100% Est. ETO	2	2	9	6	1	0	19
120% Est. ETO	1	5	3	4	2	3	18
Total	6	21	39	25	6	5	102

Table 3.10 — Mean heights (in cm) and numbers of large leaves (>2cm) of trees planted as acorns with augered planting sites (15 sites/treatment planted).

Treatment	n	Height		No. of lg. Leaves	
		Mean ± S.D.	P-value[a]	Mean ± S.D.	P-value
Feb. 1990					
Augered	12	17 ± 13	< 0.05	30 ± 32	n.s.
Comparison	12	11 ± 3		13 ± 5	
Jan. 1991					
Augered	12	39 ± 60	n.s.	>39[b] ± 39	< 0.01
Comparison	8	9 ± 4		7 ± 9	

[a] Kolmogorov-Smirnov contingency test.

[b] Trees with more than 100 leaves were recorded as having 100 leaves, so actual mean is slightly more than 39.

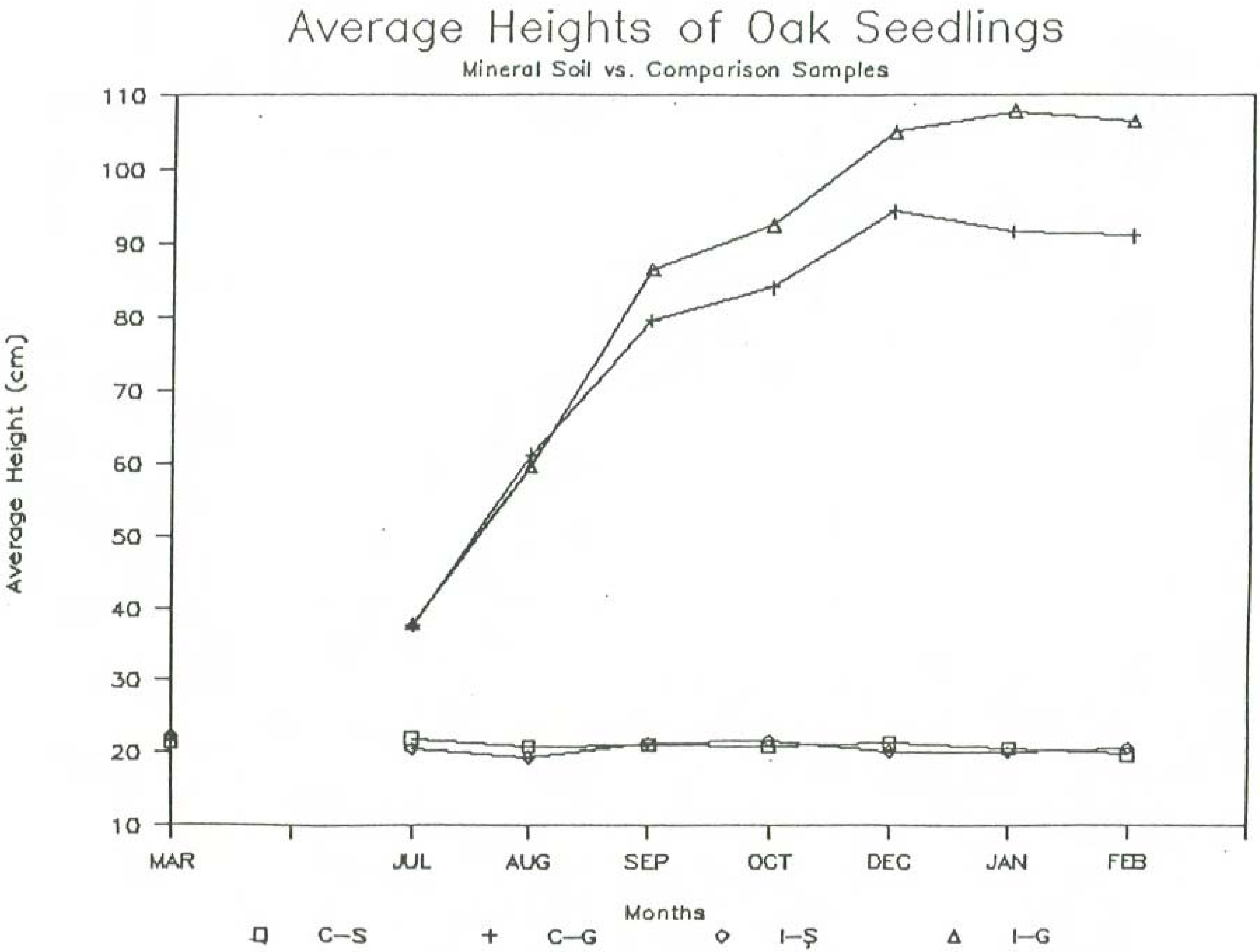


Figure 3.1. The average heights of Englemann oak seedlings planted at one year of age. Inoculated seedlings are represented by open triangles (inoculated seedlings which grew) and diamonds (inoculated seedlings which were stunted). Comparison seedlings are represented by crosses (comparison seedlings which grew) and open boxes (comparison seedings which were stunted). Initial heights of the four groups are marked on the abscissa.

STUDY 4. EFFECT OF CONTROLLED-RELEASE FERTILIZERS ON THE SURVIVAL AND GROWTH OF OUT-PLANTED BLUE AND VALLEY OAK ACORNS
Lead Investigator: Robert H. Schmidt

INTRODUCTION

Successfully planting collected acorns on hardwood rangelands is a challenging task. All of the mortality factors which affect naturally-sown acorns also affect acorns planted by humans. Acorns need to germinate, develop a deep root system, and establish sufficient photosynthetic area to survive and grow. Growth needs to proceed at a pace fast enough to eliminate the potential damage caused by animals browsing on the foliage and stem.

Research has demonstrated the importance of site preparation for enhancing the survival and growth of outplanted acorns and seedlings. However, the general benefits of fertilization are not well understood. Research results are mixed, with some species of oak responding well to fertilizer and others not. In addition, studies have demonstrated that increased plant nutrition at the earliest stages has positive long range benefits in regards to growth and survival. Individuals and agencies currently involved in oak planting in California are using a variety of fertilizers and application rates in their planting projects without adequate knowledge of the need for fertilization. Thus, it is appropriate and important to test a variety of fertilizer schemes and to assess their impact on growth and survival of blue and valley oaks. This study was designed to test four different fertilization systems on the growth and survival of these native California oaks.

METHODS AND MATERIALS

The research site selected for this experiment was the University of California Hopland Field Station in southeastern Mendocino County. Blue and valley oak acorns were collected from the site in the fall of 1988. The acorns were picked from trees, immersed in water so that floating acorns could be removed, dried with blotting paper, then stored in zip-lock plastic bags at 34° F until ready for planting.

The planting site was selected in a pasture that had previously been cleared, but contained a remnant stand (less than 10% canopy coverage) of both blue and valley oaks. Typical rangeland soils were of the Sutherlin series, developed from hard sandstone and shale. This soil is moderately shallow, with good to imperfect drainage, and generally deficient in nitrogen, phosphorus, and sulfur. The site was enclosed with a deer-proof wire fence in late November, 1988. The site was prepared in late November-early December with augered holes at each planting spot. A truck-mounted, 23 cm auger was used to drill 960 holes (480 for each species), each 91 cm deep. A block design was utilized for the experiment, with each species assigned 8 blocks. Within each block, there were six rows, each with 10 augered holes (8 x 6 x 10 = 480 holes). The rows were separated by 137 cm, and planting holes were 91 cm apart. Six treatments were randomly assigned row positions within a block. The treatments for both the blue and valley oak plots were as follows:

- **Control 1** No fertilizer; planted on 27 February 1989.
- **Control 2** No fertilizer; planted on 12 April 1989)
- **Agriform 8** Two Agriform 10 gram tablets, composition 20-10-5, planted 8 inches (20 cm) deep; tablets planted on opposite sides of the 9 inch (23 cm) augered hole with acorns planted in the center; planted on 12 April 1989.

- **Agriform 24** Two Agriform 10 gram tablets, composition 20-10-5, planted 24 inches (61 cm) deep; tablets planted on opposite sides of the 9 inch (23 cm) augered hole with acorns planted in the center; planted on 12 April 1989.

- **Agriform 8/24** Two Agriform 10 gram tablets, composition 20-10-5, one planted 8 inches (20 cm) deep, the other 24 inches (61 cm) deep; tablets planted on opposite sides of the 9 inch (23 cm) augered hole with acorns planted in the center; planted on 12 April 1989.

- **Osmocote** 28 grams of controlled release Osmocote fertilizer, composition 14-14-14; mixed with soil 8 inches (20 cm) below soil surface in augered hole; planted on 12 April 1989.

The rate of fertilization was selected so that each fertilized seedling would receive 4 grams of nitrogen. Treatments Control 1 and Control 2 did not receive any fertilizer and differed solely by planting date. Both fertilizers were produced by Sierra Chemical Company, Milpitas, California.

After the late November and early December augering, soil was returned to the holes and settled with rainfall. Planting was originally scheduled for late February, 1989, but rain following the initial Control 1 planting prevented additional planting, and it was not until early April that the soil was sufficiently dry to attempt the remaining plantings. An earlier planting would have resulted in acorns planted in standing water or fertilizer mixed with clods of soil rather than being uniformly distributed within the hole. Planting was continued and completed on 12 April 1989.

The planting procedure was straightforward. For the valley oaks, only pre-germinated acorns were used (radicle emergence was initiated in storage). A single acorn was planted on its side 5 cm below the surface of the soil. For treatments Agriform 8, Agriform 24, and Agriform 8/24, a hollow PVC tube was used to ensure proper placement of the Agriform tablets at the required depths (8 or 24 inches; 20 or 61 cm). An Agriform tablet was dropped into the tube and a smaller diameter PVC pipe was pushed inside the larger tube to hold the tablet against the bottom of the hole. Both tubes were then removed, leaving behind an Agriform tablet buried at the desired depth. For the Osmocote treatment, the measured amount of fertilizer was mixed with soil 20 cm deep in the hole, which was then filled in with the remaining soil. The only variation for the blue oak experiment was that germination for the acorns in storage had been very slow, so that two acorns were planted in each hole. These included acorns with and without radicles. As these emerged, they were thinned to one per planting spot. The remaining acorns were planted in Leach supercells in a greenhouse.

Weed control was strictly mechanical. Mowers were used to keep down competing vegetation between rows, and a weed whip and hand weeding were utilized to remove vegetation (primarily annual grasses and filaree) from the planted holes. On June 5, all emerging seedlings were covered with a plastic mesh screen ("Hopland tent No. 2," Forest Protection Products, Inc.). The tent was primarily used to prevent grasshoppers from consuming seedlings and to provide some shade. Because of the late planting date, planted acorns were watered on April 13 (1 gallon; 3.8 l), and May 18 (0.5 gallon; 1.9 l), with late spring and early summer rainfall adding moisture on June 4 (.46 inches; 1.2 cm) and June 25 (.26 inches; 0.7 cm). Rainfall began again in late September (over 2 inches; 5 cm).

Seedlings were monitored and measured throughout the first summer. Data on emergence and growth were collected on April 27, May 17, May 25, June 6, June 23, July 12, July 26, August 9, September 29 (all in 1989), and on February 24, 1990. Valley oak seedlings were also evaluated on November 8, 1990 and August 7, 1991. Statistical analysis (StatView SE+Graphics) utilized analysis of variance with a Fisher's protected least significant difference test to compare individual treatment means. The $\alpha = 0.05$ level of significance was used throughout.

RESULTS

Number of surviving seedlings - valley and blue oak

For all treatments, maximum seedling counts in 1989 never exceeded 52.5% (n = 42 out of 80 planted for each treatment) for valley oaks and 23.8% (n = 23 out of 80) for blue oak (Figures 4.1 and 4.2). For both species, the greatest number of seedlings was achieved with treatment Control 1, the earliest planting date. For valley oak, pooling all treatments, the average highest seedling count was 28.3%. Using this as an expected value, treatments varied from it significantly ($x^2 = 37.066$, 5 d.f, $p < 0.0001$), with treatment Control 1 being much better than the rest, and treatment Osmocote being much worse. A similar pattern held for blue oak, with treatment Control 1 again having the greatest number of seedlings and none of the Osmocote-treated seedlings emerging. For blue oak, pooling all treatments maximum seedling counts averaged 6.7%.

Valley oak acorns planted in the greenhouse (with radicles already protruding) had a 97% emergence rate, indicating that the field plot was a hostile environment to the young plants. The picture was not so obvious with the blue oaks. Forty-seven percent of the blue oak acorns planted in the greenhouse without radicles produced seedlings, while only 15% of the acorns with radicles produced seedlings.

By 1991, seedling counts had increased for all valley oak treatments and were 55%, 33.8%, 32.5%, 31.2%, 37.5%, and 22.5% for the Control, Control 2, Agriform 8, Agriform

24, Agriform 8/24, and Osmocote, respectively. Additional seedlings had emerged in both 1990 and 1991, although most additional seedlings emerged in 1990. Surprisingly, the number of seedlings in the Osmocote-treatment went from 7.5% in 1989 to 22.5% in 1991, a three-fold increase. However, earlier planted acorns (Control 1) remained the treatment with the highest number of seedlings.

In summary, planting date seemed to have a greater effect on emergence and survival than fertilizer treatment, with the exception of the Osmocote treatment, which consistently resulted in lower seedling counts. Although greenhouse-planted valley oak acorns emerged much better than the acorns planted in the test plot, blue oak acorns planted in the greenhouse demonstrated a low emergence level. Some valley oak acorns which failed to emerge in the field in 19889 did so in subsequent years.

Growth of seedlings - valley oak

There was variability in first-year growth of valley oak seedlings planted with different treatments (Figure 4.3). Low emergence rates prohibited a 2-way analysis of variance (treatments and blocks), so all similar treatments were combined irrespective of block and a one factor analysis of variance (ANOVA) was performed, focusing on treatment effects.

By 17 May 1989, 89 days following the planting of the Control 1 acorns and 35 days following the planting of the rest of the treatments, there were no significant differences between treatments (Table 4.1), although the Control 1 seedlings were generally taller than the rest ($\bar{x}$= 5.9 cm). However, 8 days later, Control 1 seedlings were significantly taller than seedlings from all other treatments (Table 4.2). Although the Control 1 seedlings did grow larger in this 8-day period ($\bar{x}$= 6.5 cm), the increasing sample size (and corresponding decrease in standard error) of the other treatments was mainly responsible for this difference being significant.

In mid-summer (9 August 1989), significant differences remained between treatments (Table 4.3). The Agriform 8 seedlings averaged 11.6 cm in height, while the Control 1 seedlings averaged 8.8 cm. Control 2 seedlings averaged 7.5 cm in height. Fisher's protected least significant difference test indicated that the height of Control 1 seedlings differed from Agriform 8/24 seedlings, and the height of Agriform 8 seedlings differed from Agriform 24, 8/24, and Osmocote seedlings ($p < 0.05$). The Control 2 seedlings, on this date, did not differ in height from any of the other treatments.

Seedling height differences remained at the end of the summer dry period (Table 4.4), even though herbivory by grasshoppers resulted in decreased mean heights for most treatments. The mean heights of Control 1, Control 2, and Agriform 8 seedlings were 8.8, 6.4, and 7.6 cm, respectively. Fisher's protected least significant difference test indicated that the heights of Control 1 seedlings differed from those of the Agriform 24 and Agriform 8/24 treatments, and that the Agriform 8 seedling heights differed from the Agriform 8/24 treatment ($p < 0.05$).

After the fall rains and the start of winter dormancy (24 February 1990), the final mean heights of all seedlings in each treatment were 9.3 cm (Control 1), 7.8 cm (Control 2), 8.1 cm (Agriform 8), 4.9 cm (Agriform 24), 5.1 cm (Agriform 8/24), and 6.6 cm (Osmocote; Table 4.5). Fisher's protected least significant difference test indicated that the heights of Control 1 seedlings differed from those of the Agriform 24 and Agriform 8/24, and that the Agriform 8 seedling heights differed from the Agriform 24 treatment ($p < 0.05$).

These differences were even more pronounced by the end of the 1990 growing season (Table 4.6), with the mean heights of all seedlings in each treatment increasing to 23.2 cm (Control 1), 10.5 cm (Control 2), 19.8 cm (Agriform 8), 12.0 cm (Agriform 24), 11.0cm (Agriform 8/24), and 10.8 cm (Osmocote). Fisher's protected least significant difference test indicated that the heights of Control 1 and Agriform 8 seedlings differed from all other treatments except for each other.

Finally, in August, 1991, mean heights of all seedlings in each treatment increased to 44.1 cm (Control 1), 21.1 cm (Control 2), 30.1 cm (Agriform 8), 25.4 cm (Agriform 24), 23.1 cm (Agriform 8/24), and 20.1 cm (Osmocote) (Table 4.7). Fisher's protected least significant difference test indicated that the heights of Control 1 seedlings differed from all other treatments.

Growth of seedlings - blue oak

There was also variability in the growth of the blue oak seedlings planted with different treatments in 1989 (Figure 4.4). As mentioned previously, none of the Osmocote-treated acorns emerged. This, and the very low emergence of most of the other treatments, prevented substantial statistical analysis. Seedling growth data for the various treatments are presented in Tables 4.8 - 4.12. Confidence intervals (t = 95%) constructed for each mean overlapped substantially between treatments, indicated there were no significant treatment effects.

Once blue oak seedlings emerged, mean heights generally remained low, ranging between 2 and 3 cm the first year. A graphic exception (see Figure 4.4), is the height for seedlings in treatment Agriform 8. The obviously different line represents a single blue oak seedling which emerged and grew taller than any of the others.

DISCUSSION

Action of Fertilizers

The chemical analysis of Agriform planting tablets and Osmocote controlled release fertilizer is outlined in Table 4.13. The longevity of the Osmocote (based on 70° F average soil temperature) is 3 to 4 months. Water vapor from the soil penetrates the resin coating of the capsules, dissolving the water soluble nutrients inside. The dissolved nutrients then gradually diffuse through the capsule into the soil. The manufacturer states that there is "virtually no risk of burning plants due to the unique resin coating on each fertilizer pill." Agriform tablets release their nutrients through a combination of bacterial action and leaching. The tablets do not dissolve. The manufacturer states that "Soil bacteria acting on the surface of the tablets gradually convert the slow-release nutrients to a form that can be absorbed by the roots." The tablets remain effective for up to 2 years.

Thus, these fertilizers differ in a number of ways. First, nitrogen is derived from different sources (urea-formaldehyde for Agriform; ammonium nitrate and potassium nitrate for Osmocote). Second, Agriform tablets, in addition to containing N, P, and K, contain Ca, S, and Fe. Finally, the method of release of these two fertilizers is different. Any of these reasons might explain the differences between the emergence and growth rates for the seedlings.

Effect of early versus late planting

The most pronounced effect resulting from early and late planting (27 February and 12 April) dates was on emergence. Valley and blue oaks planted in late February emerged earlier and had higher total seedling counts than did those planted in early April

(Figures 4.1 and 4.2). This supports evidence presented by other researchers and restoration practitioners that earlier planting dates tends to be more successful. However, emergence was delayed in many instances, with some seedlings failing to emerge until the 1990 and 1991 growing seasons. Even so, planting acorns earlier consistently resulted in higher emergence and survival rates.

For both valley and blue oak seedlings, there was no significant planting date effect on height at the end of the fall 1989 growing period. There was a significant difference for valley oak seedlings in late May, 1989 (6.5 cm versus 1.9 cm for Control 1 and Control 2 treatments, respectively); however, by early August this difference disappeared (Figures 4.3 and 4.4). By 1990 and 1991, however, Control 1 seedlings were much taller than Control 2 seedlings, averaging more than twice as tall.

Effects of different fertilizers

No fertilizer treatment performed significantly better than Control 2 (no fertilizer treatment) for either blue or valley oak in 1989. However, for valley oak acorns in 1989, the Agriform 24 and the Agriform 8/24 treatments consistently produced smaller seedlings, especially compared to the Agriform 8 treatment. This effect was more pronounced in 1990, when Agriform 8-treated seedlings out-performed both Control 2 seedlings and the other fertilizer-treated seedlings. However, this effect disappeared by 1991.

The Agriform manufacturer recommends placement of Agriform tablets at a depth of 10-25 cm below the surface and to the side of a plant. Deeper planting of the tablets was originally proposed because it was thought that a deep placement might allow nutrients to be available to the oak seedling but too deep for competing vegetation, especially grasses. Deeper planting of the tablets may have 1) decreased the amount of nutrients available because the tablets were below the reach of most of the feeder roots, especially for smaller seedlings, or 2) the planting depth may have retarded the bacterial growth required for nutrient release.

Osmocote was the most surprising fertilizer treatment, since it is widely used as the fertilizer of choice for many oak planting operations. For valley oaks, mean heights of seedlings were similar to those observed with the Agriform 24 and Agriform 8/24 treatments. The most pronounced effect was the suppression of seedling emergence for valley oaks (and possibly blue oaks, although the low emergence rate of other treatments also prohibits definite conclusions). Except for 6 instances, valley oak acorns planted above Osmocote fertilizer failed to emerge (Figure 4.1). One possible interpretation of this is that Osmocote fertilizer placed below ground in the manner of this experiment, may cause injury to feeding roots and/or the main tap roots of young seedlings. This may be avoided by using less fertilizer, by only using Osmocote as a top dressing fertilizer, or by application to the side of acorns or seedlings. It may be that this effect is more pronounced with planted acorns than planted seedlings, since seedlings would already have tap roots in or below the fertilizer before significant nutrient diffusion occurs. It is not known whether the formulation or placement technique of Osmocote had a negative (or non-positive) effect on seedling emergence. However, by November, 1990, there were 19 valley oak seedlings from the Osmocote. Although this percentage was still the lowest for all treatments, it did demonstrate a remarkable capability for delayed emergence in acorns.

CONCLUSIONS

This project suggests that the effect of fertilization on planted oak acorns may be slight in the first year after planting, since no fertilizer treatment produced seedlings with a mean height larger than that of the control (Control 2) in 1989. By the second year, Agriform 8 treatments produced seedlings with mean heights similar to those of the earlier-planted acorns (Control 1), and significantly greater than those of the other fertilizer treatment. However, this significant effect disappeared by 1991 although the Agriform 8 seedlings still had the highest average height of all fertilizer treatments. These marginal results suggest that fertilization is probably not cost effective in rangeland soils such as those found in north-coastal California. Some fertilization practices may in fact inhibit seedling emergence and growth. Planting date has a more pronounced effect on both emergence and seedling height, with earlier planting favoring more emergence and taller seedlings.

Future studies of fertilization may find it useful to observe the effects of fertilizer - irrigation interactions, fertilizer - weed control interactions, and the variable effects of alternative fertilization placement.

Table 4.1 —Summary of valley oak seedling height data collected on 17 May 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	35	5.9	0.655
Control 2	2	2.0	0.000
Agriform 8	4	1.8	0.479
Agriform 24	2	2.0	1.000
Agriform 8/24	3	1.3	0.333
Osmocote	1	5.0	--

One factor ANOVA, F=2.298, p=0.0625

Table 4.2 —Summary of valley oak seedling height data collected on 25 May 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	36	5.9	0.630
Control 2	9	1.9	0.539
Agriform 8	11	2.2	0.497
Agriform 24	8	1.9	0.507
Agriform 8/24	12	1.8	0.376
Osmocote	3	2.8	1.167

One factor ANOVA, F=9.783, p=0.0001

Table 4.3 —Summary of valley oak seedling height data collected on 9 August 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	28	8.8	1.027
Control 2	11	7.5	1.893
Agriform 8	10	11.6	2.535
Agriform 24	10	6.6	1.011
Agriform 8/24	11	4.3	0.829
Osmocote	6	5.3	0.989

One factor ANOVA, F=2.543, p=0.0358

Table 4.4 —Summary of valley oak seedling height data collected on 29 September 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	41	8.8	0.956
Control 2	17	6.4	1.548
Agriform 8	16	7.6	2.023
Agriform 24	18	5.4	0.747
Agriform 8/24	20	3.8	0.638
Osmocote	6	4.7	1.116

One factor ANOVA, $F=2.734$, $p=0.0228$

Table 4.5 —Summary of valley oak seedling height data collected on 24 February 1990.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	41	9.3	0.946
Control 2	14	7.8	1.791
Agriform 8	20	8.1	1.566
Agriform 24	26	4.9	0.514
Agriform 8/24	20	5.1	0.567
Osmocote	4	6.6	2.173

One factor ANOVA, $F=3.088$, $p=0.0117$

Table 4.6 —Summary of valley oak seedling height data collected on 8 November 1990.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	43	23.2	2.032
Control 2	27	10.5	1.434
Agriform 8	25	19.8	4.138
Agriform 24	31	12.0	1.123
Agriform 8/24	31	11.0	1.148
Osmocote	19	10.8	1.337

One factor ANOVA, $F=7.773$ $p=0.0001$

Table 4.7 —Summary of valley oak seedling height data collected on 7 August 1991.

Treatment	Count	Mean height (cm)	S.E. (cm)
Control 1	44	44.1	3.992
Control 2	27	21.1	2.461
Agriform 8	26	30.1	5.447
Agriform 24	25	25.4	2.446
Agriform 8/24	30	23.1	2.933
Osmocote	18	20.1	2.143

One factor ANOVA, F=7.186 p=0.0001

Table 4.8 — Summary of blue oak seedling height data collected on 17 May 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	21	2.7	0.156
Control 2	0	--	--
Agriform 8	0	--	--
Agriform 24	0	--	--
Agriform 8/24	0	--	--
Osmocote	0	--	--

Table 4.9 — Summary of blue oak seedling height data collected on 25 May 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	23	2.3	0.175
Control 2	0	--	--
Agriform 8	0	--	--
Agriform 24	0	--	--
Agriform 8/24	1	1.0	--
Osmocote	0	--	--

Table 4.10 —Summary of blue oak seedling height data collected on 9 August 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	21	2.6	0.219
Control 2	3	3.0	1.000
Agriform 8	1	8.5	--
Agriform 24	2	3.0	0.000
Agriform 8/24	3	2.3	0.333
Osmocote	0	--	--

Table 4.11 —Summary of blue oak seedling height data collected on 29 September 1989.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	21	2.8	0.260
Control 2	2	2.8	0.250
Agriform 8	1	7.5	--
Agriform 24	2	2.2	0.250
Agriform 8/24	3	2.2	0.167
Osmocote	0	--	--

Table 4.12 —Summary of blue oak seedling height data collected on 24 February 1990.

Treatment	*Count*	*Mean height (cm)*	*S.E. (cm)*
Control 1	17	3.2	0.372
Control 2	2	4.0	1.500
Agriform 8	1	8.0	--
Agriform 24	1	3.0	--
Agriform 8/24	2	3.5	1.000
Osmocote	0	--	--

Table 4.13 —Analysis of Agriform 20–10–5 planting tablets and Osmocote 14–14–14 controlled release fertilizer. Data provided by manufacturer, and is expressed in percentages (by weight).

	Agriform tablets[1]	*Osmocote*[2]
Total Nitrogen	20.0	14.0
(water soluble organic N)	(7.0)	
(water insoluble organic N)	(13.0)	
(ammoniacal N)		(6.6)
(nitrate N)		(7.4)
Available Phosphoric Acid	10.0	14.0
Soluble Potash	5.0	14.0
Calcium	2.6	0.0
Sulfur	1.6	0.0
Iron	0.35	0.0

[1] derived from urea-formaldehyde, calcium phosphates, potassium sulfate, calcium sulfate, and ferrous sulfate.

[2] derived from ammonium nitrate, ammonium phosphates, calcium phosphates, and potassium nitrate.

Figure 4.1 Number of valley oak seedlings observed on different sampling dates from different fertilizer treatments

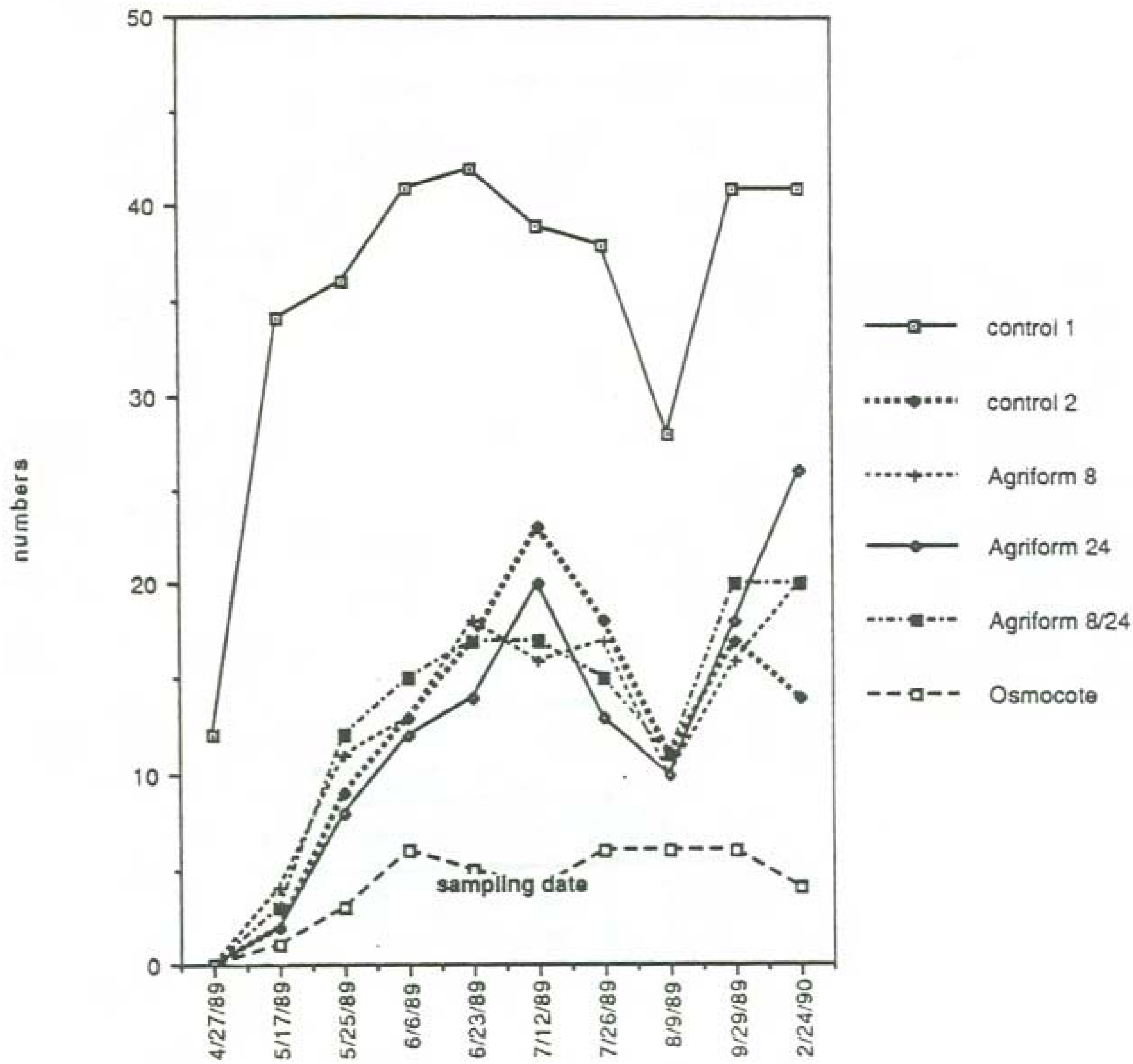


Figure 4.2 Number of blue oak seedlings observed on different sampling dates, from different fertilizer treatments

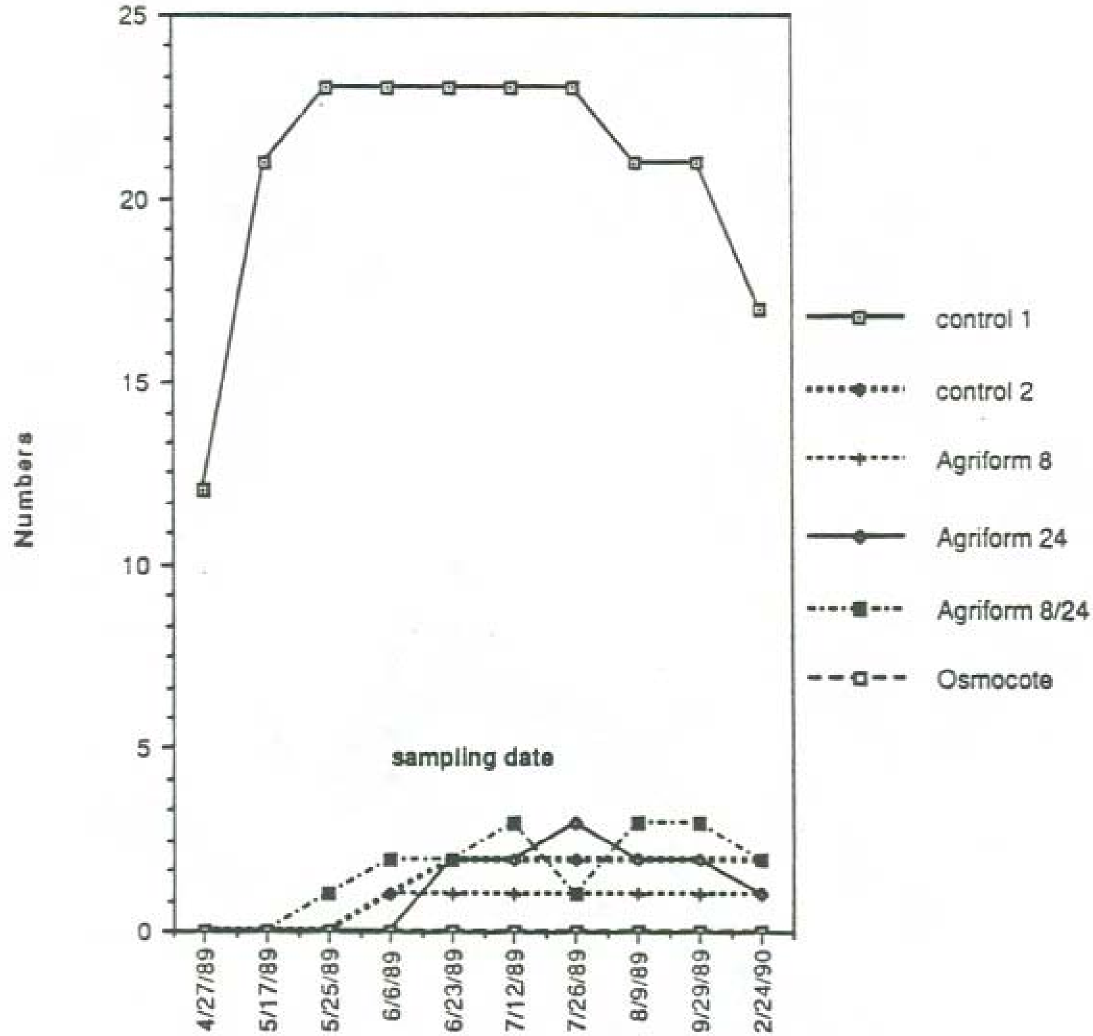


Figure 4.3 Mean heights (cm) of valley oak seedlings receiving fertilizer treatments (on different sampling dates)

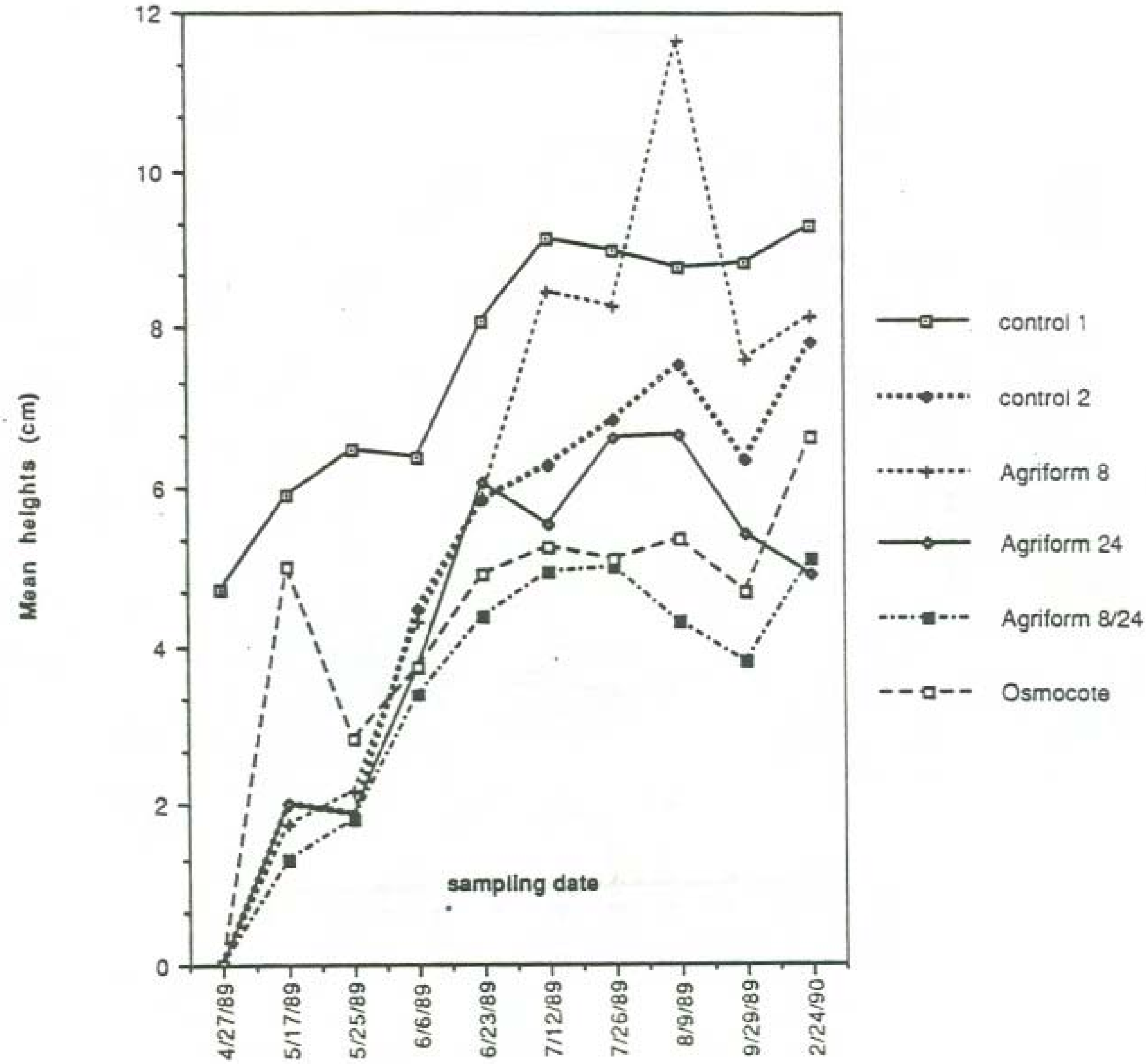
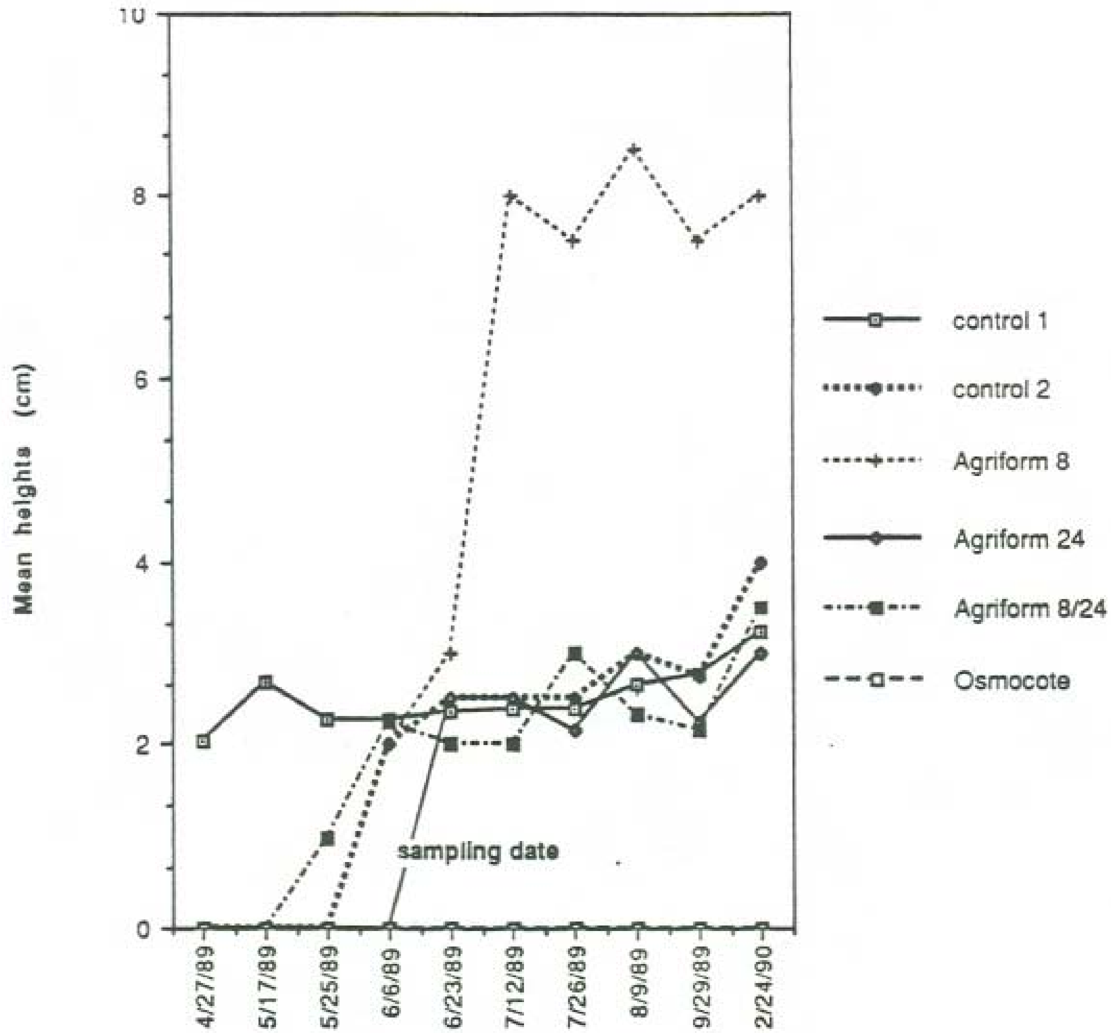


Figure 4.4 Mean heights (cm) of blue oak seedlings receiving different fertilizer treatments (on different sampling dates)



STUDY 5. LIFTING AND STORING BAREROOT BLUE OAK SEEDLINGS
Lead Investigator: Doug McCreary

INTRODUCTION

Widespread efforts to artificially regenerate native oaks in California will require the production of large numbers of seedlings. However, currently relatively few oak seedlings are produced in the state and most of these are destined for landscape settings. To date, production techniques have focused on producing large container plants. As a result, relatively little is known about bareroot culturing techniques.

While little is known about growing native oaks, there is abundant information on growing conifers. This body of knowledge indicates that the physiological condition of seedlings at the time they are outplanted is critical to their success. Two nursery practices that can greatly affect the condition of bareroot seedlings are lifting and storage. In general, it has been reported that long storage and lifting seedlings either early in the fall or late in the spring can be detrimental to seedling vigor and outplanting performance (Hermann, *et al.* 1972). There can also be an interaction between these variables. Storage of stock lifted in mid-winter, for instance, has been found to have little effect while storage of fall-lifted stock can be lethal (Fowells and Schubert, 1954). Since it has been clearly shown that lifting date and storage can profoundly impact the physiological condition of seedlings, the following study was designed to examine the effects of these two treatments on blue oaks. Current research also indicates that the root growth capacity, or RGC, of seedlings can be used as a reliable indicator of seedling quality, so this procedure, as well as field planting performance, was used to evaluate the impacts of various lifting and storage treatments.

METHODS

In fall and winter of 1987 several thousand blue oak acorns collected at a site in Butte County (200 m elevation) were sown at the California Department of Forestry nursery in Magalia as part of a study investigating the effects of sowing date and undercutting on bareroot seedling production. After one year in the nursery, there were marked differences in seedling morphology as a result of undercutting treatment, but little effect from different sowing dates. Seedlings from treatments receiving both an early (May) and late (August) undercutting treatment were deemed best in terms of overall size, cull percent and root development. Only seedlings from this multiple undercutting treatment were used in the current study. These seedlings had been grown in standard nursery beds at a density of 12 to 14 per square foot.

Lifting Dates

Seedlings were lifted on four separate dates. The initial study plan called for lifting at the beginning of December 1988, and January, February and March, 1989. As planned, the first lifting date was December 2. Unfortunately it was impossible to lift seedlings at the beginning of January, since the nursery was covered with over a foot of snow. By January 20, there was still substantial snow at the nursery, but it was decided to dig the seedlings out and lift them anyway. Due to the weight of the snow, most of these seedlings were bent over and remained that way during lifting and subsequent planting. The third and fourth lifting dates were February 3 and March 6.

On each lifting date seedlings were shovel-lifted from two 4.6 m long beds. Approximately 150 seedlings from three separate locations within each bed were lifted (one from each of the original sowing dates).

After lifting the seedlings were bulked, culled and randomly sorted into three equal groups. Seedlings with tops shorter than 6 cm or with calipers less than 3 mm or with poorly developed root systems were discarded. Those remaining were randomly sorted into three groups of approximately 50 each -- one for each of the storage treatments. Seedlings from the no storage treatment were planted the same day in the growth-room trial and within three days in the field as described below. Those from the other two storage treatments were placed in a cooler maintained at 0-5°C. Since there were four lifting dates and three storage treatments, there were 12 treatment combinations overall.

Field Planting

The field plot consisted of 360 planting spots spaced 1.2 m apart in each direction. This plot was located within a deer and cattle proof exclosure. In late November 1988 each planting spot was augered to a depth of 90 cm using a 15 cm diameter auger mounted on a tractor. After augering the soil was put back in the holes and a 21-gram fertilizer tablet (Agriform 20-10-5) was placed approximately 25 cm below the soil surface. Just before the plot was augered, it was sprayed with glyphosate to eliminate current vegetation. Subsequent sprays in January and April were used to control later germinating weeds. Since the oaks had leafed out by the last spray date, the herbicide was directed away from the seedlings. Some minor leaf scorching occurred on a few seedlings but it did not appear that any seedlings were killed or severely damaged by the herbicide.

The field plot was arranged in three blocks with 12 rows of 10 seedlings each per block. For each lifting and storage combination, one randomly assigned row per block was planted. Soil conditions at time of planting varied. On the first date, the soil used to fill around the seedlings was quite dry since it had not rained since the augering took place. Therefore, each of the 30 seedlings planted on that first date was given approximately 150 ml of water. For all subsequent plantings, no supplemental water was provided. On several of the planting dates, the soil was saturated and there was standing water in some of the holes. These holes were noted, but it turned out that overall survival in these planting spots was similar to that for the plot as a whole.

For each of the lifting/storage combinations, all seedlings were planted in a single day. Care was taken not to "J" root the seedlings and soil was gently packed around the roots. Since there had been no rainfall between augering and the first planting, about half of the seedlings from the first lifting/no storage treatment sunk several inches as the soil settled after the first rains. Several seedlings were partially covered up and apparently killed because of this sinking. This was not a problem for any of the later plantings.

After planting, each seedling was covered with an 60 cm tall cylinder of aluminum screen to prevent small rodent and insect damage. In the spring and summer after planting, seedlings were evaluated twice a week to determine bud-burst date and date of subsequent flushes. In fall 1989 and fall 1990, each seedling was evaluated for survival, total height and caliper.

Growth Room Planting and Evaluation

Of the 50 seedlings lifted from each lifting/storage combination, 15 were chosen for growth-room evaluation. These were randomly sorted into three groups of 5 seedlings and each group was planted in a 20 cm diameter 7.5 liter pot. A standard potting mix consisting of peat moss, vermiculite and fir bark was used. After potting, seedlings were placed in a growth room at the Environmental Horticulture facilities on the U.C. Davis campus and maintained for four weeks. Pots from the various treatments were randomly positioned in the growth room. During this period, seedlings were exposed to a 16-hour photoperiod with constant 21 °C temperature, and were watered regularly. After exactly 28 days, the seedlings were removed from the growth room and evaluated for new root and shoot growth. The seedlings were gently removed from the potting medium, washed, and a number of new white root tips greater than 3 mm in length was counted. The total length of new roots (to the nearest 0.5 centimeter) for each new root was also recorded. After harvest, the potting mix was carefully examined and any broken new roots were located. These were measured and added to the pot totals. The number of new elongating shoots (longer than 3 mm) was also counted. These shoots were then dried and weighed. Finally, caliper was measured and each seedling was cut at the cotyledon scar. The shoots and roots were placed in paper bags, dried, and weighed to determine shoot weight, root weight, total weight and shoot-root ratio.

Statistical Analysis

For the field trial, row totals were calculated for first season (1989) survival, height, caliper, average leaf-out date and number of flushes. After the second growing season, row totals for survival, height, caliper, height increment, and caliper increment were also calculated. All data were analyzed using standard analysis of variance procedures for a randomized block design.

If there were significant interactions between lifting date and storage for any variable, the table of interaction means was examined to determine what caused the interaction and how it might modify the interpretation of significant main effects. Wherever significant differences were found, a least significant difference test (LSD) for the main effects (lifting dates and storage intervals) was also conducted to determine which treatment means were significantly different from one another. Tables 5.1-5.4 list these means for the field trial for both the first and second year. Tables 5.5 and 5.6 list the means for the growth-room trial. For each variable and main effect, means not followed by the same letter are significantly different at the $p \leq 0.05$ level. If no letters are present, the analysis of variance did not show a significant difference for that variable. Tables 5.7, 5.8 and 5.9 show the averages of each lifting date/storage combination for each variable in the field and growth-room trials.

For the growth-room trial simple correlations were also calculated between seedling size variables (caliper, shoot-length, shoot weight, root weight, total weight, and shoot-root ratio) and response variables (number of new roots, length of new roots, number of shoots, weight of shoots) to determine if initial size was related to the ability to grow roots or shoots.

RESULTS

Field Trial

There were significant differences for most variables for both lifting date and storage interval. There were also often significant lifting x storage interactions. In general these were due to the fact that storage for the first two lifting dates had little or no effect, while long storage (2 months) resulted in poor field performance for the last two lifting dates. Each variable is discussed below.

Survival. In general, survival was high, averaging 84% for the entire planting the first year and 83% the second year. There were significant differences between lifting dates, which ranged between 97% and 64% the first year and between 98% and 63% the second year. There were also significant differences among storage intervals. While no storage or one month of storage resulted in 90% survival the first year and 89% the second year, overall survival of seedlings stored for two months was only 70% and 69% respectively for the first and second year. There were also strong lifting x storage interactions. These resulted from the fact that differences among storage intervals were quite small for the first two lifting dates, while for the last two dates, 2 months of storage resulted in a pronounced reduction in survival.

Height and Height Increment. There was a general trend for seedlings that were lifted earlier to be taller. Average height of seedlings from the first lifting date was 37 cm in 1989 and 81 cm in 1990, compared to a height of only 22 and 51 cm for those from the fourth lifting date. Seedlings lifted on the first date also had the greatest height increment during the second growing season. While there were no significant differences in total height for either the first or second year among storage intervals, the seedlings stored the longest were the shortest. Seedlings stored for 2 months also had significantly smaller height increment the second year. There was also a pronounced interaction between lifting and storage. As with survival, for the two first lifting dates storage had little adverse effect, while for the third and fourth dates, seedlings receiving 2 month's storage were much shorter.

Caliper and Caliper Increment. Trends for caliper were similar to those for height in that the earlier lifted seedlings had the greatest calipers and the latest lifted seedlings had the smallest calipers. The earliest lifted seedlings also had significantly greater caliper increment the second year. However, there were no differences in caliper among storage treatments either year and there were no significant interactions.

Leaf-Out Date. Of all of the variables evaluated, leaf-out date was most dramatically affected by both lifting and storage. Later lifting resulted in later leaf out and there was a significant difference between each lifting date. Similarly, there were significant differences between each storage treatment, with later leaf out for longer storage. The significant interaction was caused by the fact that storage from the first lifting date had little or no effect, while longer storage for subsequent liftings resulted in delayed leaf out.

Number of Flushes. Almost all of the seedlings in this study had multiple flushes, with an average of 2.9 flushes for each surviving seedling during the first growing season. The number of flushes was related to lifting date, with the greatest number for the earliest lifting and the lowest number for the latest lifting. The longest storage also resulted in the fewest flushes. This was largely due to the fact that the seedlings from the last two lifting dates that were stored for two months had the least flushing of any of the treatment combinations. However, long storage had no detrimental effect on seedlings from the first two lifting dates. As a result, there was also a significant interaction.

Growth-Room Trial

The results from the growth room trial were disappointing in that the data was quite erratic and inconsistent and few general trends or patterns could be detected. For some harvests almost no new roots were produced, while for others, almost every seedling produced many new roots. However, these changes appeared somewhat spurious and random and not related to either lifting or storage. Variability between pots was also quite high and there were few significant differences between treatments for either number of roots or total length of new roots. These variables are described individually below.

Number of roots. While there were no significant differences for lifting dates or storage, the first and last lifting dates had the highest averages, as did the longest storage.

Total length of roots. Not surprisingly, the total length of new roots was very similar to the number of new roots. Again, the first and last lifting dates had the greatest total length of new roots. The only significant difference was for lifting date 3, however, which had shorter new roots than lifting dates 1 or 4. There were no differences between storage treatments. However there was a significant lifting x storage interaction which resulted from the fact that for lifting dates 1 and 4 there were roughly similar numbers of roots for storage intervals, while for lifting dates 2 and 3, total length varied greatly over storage intervals, but with no consistent pattern.

Number of new shoots. The first and last lifting date had significantly more new shoots than the middle two. The no storage treatment also had significantly more new shoots than the other two treatments. A significant interaction was due to the fact that the rankings of storage treatments were different for each lifting date.

Weight of new shoots. As with the number of new shoots, there were significant differences among lifting dates, with the first and last having the greatest total shoot weight. However, contrary to the previous variable, the two-month storage treatment actually had the greatest weight of new shoots, indicating that the average weight per new shoot was the greatest for seedlings from this treatment. The significant interaction was again due to the different rankings for storage treatments between lifting dates. However, there was no discernible pattern.

Correlation of growth room variables with initial seedling size. There were no significant correlations between any of the size variables (root weight, shoot weight, shoot length, total weight, caliper, shoot/root ratio) and either of the root growth variables (number of new roots or length of new roots). A similar comparison with shoot-growth variables indicated that larger seedlings tended to have more active shoots, but that there was no relationship between seedling size and the weight of new shoot growth. Altogether these results suggest that initial seedling size had little to do with the responses evaluated.

DISCUSSION

This is the first study we are aware of where native California oaks produced in a bareroot nursery were outplanted and evaluated. The field data clearly indicate that bareroot seedlings have the potential for high survival and vigorous growth. As indicated previously, overall survival was over 84% in 1989 and over 83% in 1990, even though some of the seedlings were planted so late the first season that they had little chance. The close similarity between first- and second-year survival suggests that once seedlings survive their first year, there is a high likelihood they will remain alive.

For the plot as a whole, average height growth was 15 cm the first year and 35 cm the second year, with a number of seedlings growing at far greater rates. Such high survival and rapid growth is quite remarkable, given the reputation of blue oaks for being difficult to establish and exceedingly slow growing. It suggests that bareroot production can play an important role in future artificial regeneration programs for this species.

The field data also indicate that both lifting and storage can influence the performance of outplanted blue oak seedings. Late lifting resulted in less survival, later and less frequent flushes, and smaller year-end seedling size. Long storage had a similar negative effect. However, the effects of storage were not the same for each of the lifting dates. In general, storage had little or no effect on seedlings lifted in December or

January, but adversely influenced field performance for those lifted in February or March. The combination of two months of storage and late lifting was particularly detrimental.

One of the most striking results from the field trial was the pronounced effect of both lifting and storage on the date when seedling first leafed out and started to grow during the first year. As noted, there were significant differences between each lifting date and storage interval. This is important because the most favorable conditions for seedling growth generally occur in the early spring when there is still abundant soil moisture. If seedlings don't get started until the last day in April (the average leaf-out date for seedlings from lifting date 4) they can't take full advantage of the environment. Such late growth initiation is, no doubt, the main reason why height and caliper growth were progressively smaller for later lifting dates and longer storage intervals. The implication from these results is that it is very important to get blue oak seedlings in the ground early in the season.

It is difficult to determine from the field data if either late lifting or long storage were physiologically damaging to seedlings per se, or if poor field performance was solely caused by less favorable environmental conditions at the time of outplanting. Clearly those seedlings that were lifted in March and stored for two months didn't get outplanted until so late in the season that soil moisture was already depleted and soils were continuing to dry out rapidly. Since air and soil temperatures were also much warmer than in previous months, it is also likely that there was greater transplant shock for seedlings taken from a cold room and planted in such a hot-dry environment.

It was hoped that the growth-room trial would help evaluate physiological condition and thereby indicate if responses were due to seedling quality or the environment. Unfortunately, as noted above, the RGC data was inconsistent and difficult to interpret. There are several possible explanations for the erratic results. First, RGC may simply not be a good predictor of blue oak seeding quality and be so inherently variable that it's very difficult to relate to the physiological condition of seedlings. This does not appear likely, however, since RGC has been shown to be a good indicator of seedling quality for a variety of tree species including several oaks. It is also possible that the experimental conditions of this study were not uniform enough over time, and that some of the treatments were exposed to different environmental conditions during their 28 day test period. Since I only visited the growth room once a month, I could not be sure that all pots were watered consistently, for instance. If watering was not uniform and some pots were allowed to dry out more than others, this could have caused some of the differences observed.

Because of the inconsistent patterns in the growth room data, it is tempting to dismiss this part of this study. However, I do feel there is some information to be gained from this experiment. In the first place the data seem to indicate that late lifting, per se, is not harmful since for three of the four variables, the greatest responses were for seedings from the last lifting date. Similarly, there was no evidence that long storage was damaging since for three of the four variables, the longest storage interval resulted in the greatest growth. Finally, even though there were extremely erratic patterns for storage intervals within lifting dates, for the last lifting date all three storage treatments had relatively high root and shoot growth. As a whole the data therefore suggests that neither lifting nor long storage were terribly damaging to seedling quality, indicating that the poor field performance for seedlings lifted on the last two dates and stored for two months was probably more the result of harsh field conditions than reduced seedling vigor.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that healthy, vigorous blue oak seedlings can be produced in bareroot nurseries. One-year old seedlings that were outplanted in an unirrigated field plot had high survival and rapid growth and after two growing seasons appear well on their way to becoming established saplings. The data also indicate that there is a fairly wide window, extending from early December until early March, during which seedlings can be successfully lifted from the nursery. Seedlings can also be stored for up to two months with little or no degradation in quality. However, field planting date is critical to outplanting performance and seedlings can be adversely affected by late lifting (February or March) and long storage. This results in such late planting that unfavorable field conditions inhibit successful establishment and rapid growth. It is therefore recommended that bareroot seedlings be lifted between early December and late February and outplanted by the first of March.

Table 5.1 — First-year field performance of seedlings lifted on different dates*

	Survival (%)	Total Height (cm)	Caliper (mm)	Number of Flushes	Leaf-Out Date
Lift 1 (Dec 3)	93[ab]	36.9	5.3[a]	3.2[a]	March 18[a]
Lift 2 (Jan 20)	97[a]	29.1	4.7[ab]	3.0[ab]	March 28[b]
Lift 3 (Feb 3)	82[b]	27.6	4.4[bc]	2.7[bc]	April 11[c]
Lift 4 (Mar 6)	64[c]	21.9	3.9[c]	2.5[c]	April 30[d]

* Values within a column that are followed by a different letter are significantly different by a Fisher's Protected LSD test ($p \leq 0.05$).

Table 5.2 — First-year field performance of seedlings stored for different intervals*

	Survival (%)	Total Height (cm)	Caliper (mm)	Number of Flushes	Leaf-Out Date
No Storage	90[a]	31.5	4.7	3.0[a]	March 25[a]
1 Month Storage	93[a]	28.4	4.6	3.1[a]	April 2[b]
2 Months Storage	70[b]	26.8	4.4	2.5[b]	April 23[c]

* Values within a column that are followed by a different letter are significantly different by a Fisher's Protected LSD test ($p \leq 0.05$).

Table 5.3 — Second-year field performance of seedlings lifted on different dates*

	Survival (%)	Total Height (cm)	Caliper (mm)	Height Increment (cm)	Caliper Increment (mm)
Lift 1 (Dec 3)	92[a]	80.8[a]	9.9[a]	43.7[a]	4.6[a]
Lift 2 (Jan 20)	98[a]	64.4[b]	8.5[b]	35.9[b]	3.9[b]
Lift 3 (Feb 3)	80[b]	56.9[b]	8.0[b]	30.3[b]	3.7[b]
Lift 4 (Mar 6)	63[c]	50.8[b]	6.5[c]	29.5[b]	2.7[c]

* Values within a column that are followed by a different letter are significantly different by a Fisher's Protected LSD test ($p \leq 0.05$).

Table 5.4 — Second-year field performance of seedlings stored for different intervals*

	Survival (%)	Total Height (cm)	Caliper (mm)	Height Increment (cm)	Caliper Increment (mm)
No Storage	89[a]	66.7	8.5	35.4[ab]	3.8
1 Month Storage	92[a]	65.8	8.4	38.2[a]	3.8
2 Months Storage	69[b]	57.2	7.8	30.9[b]	3.5

* Values within a column that are followed by a different letter are significantly different by a Fisher's Protected LSD test ($p \leq 0.05$).

Table 5.5 — Root and shoot growth after 28 days in a growth room for seedlings lifted on different dates*

Lifting Date	Numbers of New Roots	Total Length of New Roots (cm)	Number of New Shoots	Dry Weight of New Shoots (gm)
1st (Dec 3)	13.1	33.1[a]	2.6[b]	1.6[b]
2nd (Jan 20)	6.4	20.5[ab]	1.4[c]	0.9[c]
3rd (Feb 3)	6.4	12.6[b]	1.2[c]	0.6[c]
4th (Mar 6)	13.4	31.7[a]	3.5[a]	2.4[a]

* Values within a column that are followed by a different letter are significantly different by a Fisher's Protected LSD test ($p \leq 0.05$).

Table 5.6 — Root and shoot growth after 28 days in a growth room for seedlings stored for different intervals*

Lifting Date	Number of New Roots	Total Length of New Roots (cm)	Number of New Shoots	Dry Weight of New Shoots (gm)
No Storage	7.7	19.9	2.9[a]	1.0[b]
1 Month Storage	8.8	26.5	1.6[b]	1.1[b]
2 Months Storage	13.0	27.0	2.1[b]	1.9[a]

* Values within a column that are followed by a different letter are significantly different by a Fisher's Protected LSD test ($p \leq 0.05$).

Table 5.7 — First-year field plot averages for all lifting date x storage combinations*

Lifting Date and Storage Interval	Survival (%)	Total Height (cm)	Caliper (mm)	Number of Flushes	Leaf-out Date
Date 1 (December 3)					
No Storage	83	36.0	5.0	3.1	March 24
1 Month Storage	97	29.3	5.1	3.2	March 17
2 Months Storage	100	45.4	6.0	3.4	March 15
Date 2 (January 20)					
No Storage	97	32.7	5.1	3.2	March 20
1 Month Storage	100	26.5	4.4	2.8	March 24
2 Months Storage	93	28.3	4.6	3.0	April 10
Date 3 (February 3)					
No Storage	100	28.6	4.6	2.8	March 23
1 Month Storage	90	32.9	4.9	3.3	April 1
2 Months Storage	57	21.4	3.8	2.0	May 10
Date 4 (March 6)					
No Storage	80	28.8	4.3	3.0	April 2
1 Month Storage	83	24.9	4.2	2.9	April 27
2 Months Storage	30	11.9	3.1	1.5	May 30

* Values represent the average per surviving seedling for three 10-seedling rows.

Table 5.8 — Second-year field plot averages for all lifting date x storage combinations*

Lifting Date and Storage Interval	Survival (%)	Total Height (cm)	Caliper (mm)	Height Increment (cm)	Caliper Increment (cm)
Date 1 (December 3)					
No Storage	80	78.6	9.5	41.7	4.6
1 Month Storage	97	69.0	9.2	39.8	4.1
2 Months Storage	100	94.9	11.0	49.5	5.0
Date 2 (January 20)					
No Storage	100	68.0	8.6	37.1	3.7
1 Month Storage	100	60.8	8.3	34.3	3.9
2 Months Storage	93	64.4	8.6	36.1	4.0
Date 3 (February 3)					
No Storage	97	61.9	8.2	33.1	3.6
1 Month Storage	87	66.3	8.5	36.2	3.8
2 Months Storage	57	42.5	7.2	21.6	3.7
Date 4 (March 6)					
No Storage	80	58.2	7.7	29.8	3.5
1 Month Storage	83	67.3	7.6	42.5	3.4
2 Months Storage	27	26.9	4.3	16.4	1.2

* Values represent the average per surviving seedling for three 10-seedling rows.

Table 5.9 — Growth room averages for all lifting date x storage combinations*

Lifting Date and Storage Interval	Number of New Roots	Total Length New Roots (cm)	Number of New Shoots	Dry Weight of New Shoots (gm)
Date 1 (December 3)				
No Storage	10.2	27.5	3.2	0.9
1 Month Storage	7.5	24.8	1.3	0.7
2 Months Storage	21.6	47.0	3.4	3.1
Date 2 (January 20)				
No Storage	3.9	10.6	1.3	0.2
1 Month Storage	14.8	48.6	2.5	2.1
2 Months Storage	0.6	2.4	0.5	0.3
Date 3 (February 3)				
No Storage	3.7	9.4	1.7	0.4
1 Month Storage	0.5	0.4	0	0
2 Months Storage	14.9	27.9	1.7	1.5
Date 4 (March 6)				
No Storage	13.2	32.2	5.3	2.6
1 Month Storage	12.3	32.4	2.5	1.6
2 Months Storage	14.7	30.6	2.8	2.9

* Values represent the average per seedling for three 5-seedling pots.

STUDY 6: PLANTING BLUE AND VALLEY OAK ACORNS AND NURSERY STOCK ON OAK-GRASSLAND RANGE

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INTRODUCTION

While procedures for propagation, culture, and management of oaks in controlled environments have been developed, relatively little is known about how to successfully establish native California oaks in a wildland setting. Factors that limit natural seedling recruitment can also prevent planted acorns and seedlings from surviving and growing. This study evaluated several planting and protection procedures. The specific objectives were to compare the field performance of directly sown acorns with 2-3 month old nursery stock, all planted under weed-free conditions, and to determine whether insect and small mammal protection is necessary for restocking areas where livestock graze. The information from this study will help define what practices are most effective for restocking oak grasslands with blue and valley oaks.

METHODS

Study Areas

Planting sites in three counties were included in this study. Each site represented conditions typical of the surrounding oak-grassland range supporting mature stands of the oaks, either blue oak or valley oak.

At the UC Hopland Field Station in Mendocino County (HFS), blue oak and valley oak were each planted on sites suitable for their growth. In Yuba County, blue oak was planted at the UC Sierra Foothill Range Field Station (SFRFS). Both blue and valley oak were planted in Monterey County, the former on the George Work Ranch (WORKRN) and the latter on the Ray Harden Ranch (HRDNRN). Characteristics of the 5 study sites are identified in Table 6.1.

Planting Material

At each site, plantings of directly seeded acorns and 2-3 month old nursery stock were made. Acorns were planted in November 1988, and nursery stock was planted in the February-March period, 1989. Emergence of acorns was recorded, and survival and growth of both classes of plant material were measured.

Acorns collected for this study represented local ecotypes collected in fall 1988. Until planting, they were maintained in cold storage (4 °C) following application of Captan to control fungi. Storage containers used were 0.08 mm clear plastic bags, each containing a small amount of "kitty litter" at the bottom to absorb excess moisture from respiration.

Nursery stock was propagated at the California Conservation Corps Nursery in Napa, California. At this facility, acorns were incubated to encourage germination. After germination, acorns were placed in 4 x 4 x 15 cm containers with a potting medium composed of vermiculite, perlite, and peat moss. Before planting, the tips of the 2-4 cm radicles were clipped to encourage multiple root formation and reduce the potential for later transplant shock.

All field planting was done in open areas away from canopy effects and under dryland conditions. Practical considerations required planting without supplemental irrigation, and earlier research conducted by Adams *Et al*. (1987) supports this approach.

Weed-free conditions were maintained in the immediate vicinity of planted acorns and nursery stock. Based on measurements of soil moisture in southeastern hardwood plantings, weed control may make up to 50% more soil moisture available (Kennedy, 1984).

Window screen was used for insect and small mammal protection at all sites. The need for protection is well documented (see Literature Review). The use of window screen also had an added benefit; screen provided shade by reducing sunlight transmission 54% (measured in $uE/M^2/s$ by a quantum sensor). The reduction in sunlight does not seriously interfere with carbon accumulation (Kevin Rice, per comm.). Griffin (1971) observed that seedling survival of blue and valley oak was higher in shade.

Field Design. Each planting site, of which there were five (two at the Hopland Field Station, one each for blue and valley oak) covered 0.4 ha. On each 0.4 ha site, 40 planting units were evenly distributed. These units represent spots were 40 trees could develop.

Selection of the number 40 was based on research conducted by Diamond *Et al.* (1987). They showed that in two north coast areas, property values were influenced by the number of oak trees per 0.4 ha. Values increased dramatically when at least 40 trees per 0.4 ha were present. In both areas, the average values declined for counts higher than 40.

Each planting unit consisted of a 1.8 x 1.8 m plot maintained free of weeds. In each of these units, both acorns and nursery stock were planted. Four subunits, two each of acorns and nursery stock, were established in each unit, and one member of each pair was protected with screen. Each subunit contained three acorns or transplants to insure adequate plant material for evaluation of survival and growth in response to protection and no protection.

The size selected for planting units allowed centers of subunits to be placed 0.6 m apart and 0.6 m from the edge of the square planting unit. This spacing provided adequate distance between subunits for access and prevented competition from herbaceous material surrounding the unit.

Only one plant in each subunit was measured. The inclusion of three plants in each subunit anticipated potential losses from factors not addressed by this study and provided greater assurance of the availability of plant material for evaluation.

Each planting unit was surrounded by temporary fencing to protect planted material from large animal herbivory and trampling. Small exclosures widely spread permitted continued grazing and control of vegetation by livestock. This also reduced the potential for damage from certain small mammals and insects by greatly reducing food and cover.

Data Analysis

Chi-square Analysis was used for initial evaluation of survival, or the number of subunits occupied at each site in spring 1990. As appropriate, survival data were pooled and used in Analyses of Variance to determine significance of treatment effects. Growth (height) data was subjected to Analysis of Variance and assumed a completely randomized design. Significant differences are reported at the 95% confidence level unless otherwise noted.

RESULTS AND DISCUSSION

Survival

Survival at each of the 3 blue oak sites was similar, and overall survival was not different in 3 of 4 treatments (Table 6.2). The difference in survival between unprotected seedlings developing from acorns and all other seedlings was highly significant ($P \leq 0.01$). In this treatment, survival was half that in the others.

Of the valley oak plantings, only survival at the HFS site followed the blue oak pattern (Table 6.2). Survival at HRDNRN was confounded early by ground squirrel (*Spermophilus beecheyi*) depredation immediately following planting of transplants. Seedlings were dug up or cut off in both screened and unscreened treatments. An intensive control program reduced further damage. Seeded acorns escaped damage, however, possibly because seedlings had not emerged when the depredation occurred. No difference between levels of protection for the 2 plant materials was recorded at HRDNRN.

Main factor effects are more clearly shown in Table 6.3. For all blue oak plantings, survival of transplants was significantly ($P \leq 0.05$) greater than that of acorns by 40%. For level of protection in all blue oak, screens were responsible for 50% more survival than recorded in unprotected treatments, a highly significant ($P \leq 0.01$) difference.

In valley oak, only the HFS planting followed the blue oak pattern of survival in the 2 classes of plant material (Table 6.3). In this planting 6% more transplants survived, but this difference was only weakly significant ($P \leq 0.10$). In the HRDNRN planting, nearly 75% more acorns survived compared with transplants, but this highly significant ($P \leq 0.01$) difference is attributed to early squirrel depredation previously described. Level of screen protection did not influence survival in either valley oak planting (Table 6.3).

In all plantings, differences in rainfall during 1988-89 are assumed to have influenced survival. However, although rainfall was higher at both HFS and SFRFS than at WORKRN, average survival of blue oak at the latter site was greater for both classes of plant material. At both HFS and SFRFS, more than 40% of the rainfall fell in March, but at WORKRN, nearly half fell in December. Distribution of WORKRN rainfall (23 cm or one-third of that at HFS and SFRFS) may have been more effective in promoting survival of an ecotype adapted to a more xeric site.

Average survival for all valley oak plant material at HFS was nearly twice that at HRDNRN. As earlier noted, transplant survival was confounded by early squirrel depredation, but acorn survival alone at HFS was 40% greater than at HRDNRN. This pattern corresponds more closely to rainfall amounts (two-thirds less at HRDNRN or 23 cm) than does the blue oak pattern, possibly because valley oak is a species adapted to more mesic conditions.

We assume that part of the blue oak survival enhanced by screens can be attributed to shade effect. It has been observed that seedlings of hardwood species, including red oak (*Q. rubra*), in the northern Midwest generally benefit from shade because it moderates temperatures and evapotranspiration (Crow 1988). When rainfall is low in California, the benefit of shade would be especially valuable.

Height Growth

Height growth of blue oak during the second season (1989-90) was strongly affected by level of protection. The overall average height of protected plant material was 2.5 times greater than unprotected acorns and transplants (Table 6.4). Although no significant difference in average height between unprotected seedlings developing from acorns and transplants was measured, protected transplants were more than one-third taller than protected seedlings developing from acorns. Rather than an interaction between main factors, this difference may be due to the advanced stage of transplant growth at planting.

The level of protection more strongly influenced growth of blue oak than did the kind of plant material from which seedlings developed. Average height of all blue oak transplants was not significantly greater than the average for all seedlings developing from acorns, 13 cm vs. 10 cm.

Rainfall in 1989-90 probably contributed to differences in growth between blue oak sites. The taller plants at SFRFS may reflect the greater percent of average precipitation that fell at this location, 100%, compared with 72% at HFS and 55% at WORKRN.

Among valley oaks, screen protection produced seedlings 30% taller, on average, than unprotected seedlings, and class of plant material did not significantly influence this difference at either site. Although class of plant material was unimportant relative to height, seedlings at HFS were nearly 3 times taller than at HRDNRN, 34 cm vs. 12 cm. This difference in growth may have been induced by the much higher rainfall at HFS in 1989-90 (64 cm vs. 27 cm).

Shade provided by screen protection undoubtedly contributed to differences in growth between protected and unprotected seedlings. The modified environment would be more favorable for growth, at least in early stages; and shade influences elongation. However, the influence of shade cannot be separated from the effect of protection from predation in this study.

CONCLUSIONS

At this point, conclusions are tentative. Three full seasons, at a minimum, are needed to provide information on survival and growth useful for recommendations. Collection of data for the minimum period will not be completed until spring 1992 when survival after 3 seasons will be recorded.

With the above qualification, 2 month old nursery stock provides higher survival compared with directly seeded acorns, at least in plantings of blue oak. The value of screen protection to enhance survival in these plantings has been clearly demonstrated; protection is recommended for all plantings on rangeland.

Table 6.1 —Characteristics of the 5 study sites.

Location	Elevation (m)	Avg. Ann. Precip. (cm)	Surface Soil Texture	Depth (cm)	Soil AWC ($cm\ cm^{-1}$)	Soil Series	Soil Family
				Valley Oak			
HRDNRN	400	46	Silty	127	0.14–0.19	Diablo	Fine, montmorillonitic, thermic clay Chromic Pelloxererts
HFS	259	94	Loam	91	0.13–0.15	Laughlin	Fine-loamy, mixed, mesic Ultic Haploxerolls
				Blue Oak			
WORKRN	640	47	Clay	86	0.16–0.19	Los Osos	Fine, montmorillonitic, thermic Typic Argizerolls
HFS	288	94	Loam	183	0.14–0.17	Hellman	Fine, mixed, thermic Mollic Palexeralfs
SFRFS	244	72	Loam	102	0.11–0.16	Argonaut	Fine, mixed, thermic Mollic Haploxeralfs

Table 6.2 — First year seedling survival (percent of planted spots occupied) in 4 treatments of blue oak (3 sites) and valley oak (2 sites) developing from seeded acorns and 2–3 month old nursery stock planted in the 1988–89 season. Survival was measured in spring 1990 after bud break.

	Treatment Survival (%)			
	Acorns		Transplants	
Site	No Screens	Screens	No Screens	Screens
		Blue Oak		
HFS	30	82	72	95
SFRFS	35	62	51	85
WORKRN	59	90	98	95
MEAN	41A[1]	78B	74B	92B
		Valley Oak		
HFS 90a[2]	98b	100b	100b	
HRDNRN	68b	65b	30a	45ab

[1] Values in line not followed by the same capital letter are different ($P \leq 0.01$) at the highly significant level by LSD Separation.
[2] Values in line not followed by the same lower case letter are significantly different ($P \leq 0.05$) by Chi-square analysis.

Table 6.3 — Average first-year main factor (plant material and protection) effects (percent survival) in blue and valley oak plantings.

	Seedling Survival (%)			
	Plant Material Factor		Protection Factor	
Site	Acorns	Transplants	Screens	No Screens
		Blue Oak		
HFS	56	84	88	51
SFRFS	48	68	74	43
WORKRN	74	96	92	78
MEAN	59	83*	85**	57
		Valley Oak		
HFS	94	100°	99	95
HRDNRN	66**	38	55	49

*,**For all blue oak, mean effects for each main factor are different at the 0.05 and 0.01 levels, respectively.

o,** Mean effects for main factors in each valley oak planting are different at the 0.10 and 0.01 levels, respectively.

Table 6.4 — Second year seedling height (cm) in 4 treatments of blue oak (3 sites) and valley oak (2 sites) developing from seeded acorns and 2 month old nursery stock planted in the 1988–89 season. Measurements made in fall 1990.

	Treatment Height (cm)			
	No Screens		Screens	
Site	Acorns	Transplants	Acorns	Transplants
		Blue Oak		
HFS	5	3	11	15
SFRFS	8	9	20	28
WORKRN	6	9	12	13
MEAN	6A[1]	7A	14B	19C
		Valley Oak		
HFS	27A[1]	32AB	35AB	42B
HRDNRN	11ab[2]	10a	14c	13abc

[1] Values in line not followed by the same capital letter are different ($P \leq 0.01$) by LSD Separation.

[2] Values in line not followed by the same lower case letter are different ($P \leq 0.10$) by LSD Separation.

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