

Constraints on Germination and Emergence of Emory Oak¹

Heather L. Germaine² Guy R. McPherson² Karin J. Rojahn²
Alicia M. Nicholas² Jake F. Weltzin²

Abstract: We investigated the effects of post-collection processing and duration of storage, acorn size, soil source, and microclimate on viability, germination, emergence, and seedling size of Emory oak, to determine if these characteristics affect its recruitment and distribution. Removal of the acorn cup increased germination up to 5-fold. Germination did not decline between 0 and 35 days of storage. Acorn size was positively correlated with viability, germination, and seedling size. Seedling emergence was not affected by soil source or microclimate. We conclude that given adequate soil moisture, germination and emergence do not limit Emory oak distribution.

Oak (*Quercus*) woodlands and savannas occupy several million hectares of arid and semi-arid wildlands in the southwestern United States and northern Mexico. These savannas and woodlands have been intensively and extensively used by humans since before the turn of the 20th century. Historically, oak trees were harvested from large areas because they were highly valued as timber for mines and as fuel for wood-fired smelters (Bahre and Hutchinson 1985). Today, local oak trees are valued for timber, food for people and animals, fuel, watershed protection, and aesthetic purposes (Young and Young 1992).

However, despite the areal extent and the economic, ecologic, and historic importance of these savanna and woodland systems, we know little about processes that contribute to their sustainability (McPherson 1992). For example, previous research suggests that oak seedling establishment in southern Arizona is variable and infrequent. Oak seedling recruitment within oak woodlands during 1989 (a relatively dry year) averaged 44 individuals/ha (Borelli and others 1994). Sanchini (1981) reported mean Emory oak seedling densities of 300, 0, and 309/ha in 1978, 1979, and 1980, respectively. Seedlings of Emory oak (*Quercus emoryi* Torr.), the dominant oak tree at lower treeline in southeastern Arizona, are relatively abundant under mature canopies, but are absent from grasslands below treeline (Weltzin and McPherson 1994, 1995). Mechanisms controlling such patterns have not been investigated. Successful management of this and other oak species will depend on a knowledge of mechanisms controlling its reproductive autecology and seedling recruitment, "bottlenecks" that potentially constrain oak tree distribution (Harper 1977).

Recognizing that little is known about the reproductive autecology of Emory oak (McPherson 1992), we chose to investigate potential constraints on germination and emergence of Emory oak. Specifically, we studied three potential limiting factors: (1) the effects of post-collection acorn processing and duration of storage on germination; (2) the relationship between acorn size and viability, germination, emergence, and seedling size; and (3) the effects of soil source and microclimate on emergence. Each of these factors was evaluated in separate experimental trials.

Emory oak is the only member of the black (or red) oak (*Erythrobalanus*) subgenus in Arizona. Unlike most black oaks, stratification does not enhance germination of Emory oak acorns, which is greatest when acorns are planted immediately after picking, and has been reported to decline with increasing time of storage to 0 percent within 60 days of storage (Nyandiga and McPherson 1992). Since such a narrow window of opportunity exists for germination to occur and because acorns are difficult to store (Nyandiga and McPherson 1992),

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²Graduate research assistant, associate professor, student research assistants, and graduate research assistant, respectively, University of Arizona, Renewable Natural Resources, Biological Sciences East Rm 325, Tucson, AZ 85721.

it becomes important for managers and researchers to know how to most efficiently store acorns while still maximizing germinability.

Managers and researchers typically separate the acorn cup (modified involucre) from the acorn shortly after acorns are harvested (Young and Young 1992). However, this is a labor-intensive activity with unknown effects on viability and germination. For example, the acorn cup may contain secondary compounds that alter the probability or timing of germination. Our observations indicate that germination occurs at the acorn's apex; thus we hypothesized that the acorn cup does not affect germination.

Previous research indicates that seed size is often positively correlated with germination and seedling growth, presumably because larger seeds have more tissue resource available than smaller seeds (Houssard and Escarre 1991). Tecklin and McCreary (1991) found that acorn mass was directly related to emergence, survival, and height of *Q. douglasii*. However, this relationship between acorn size and seedling success has not been investigated for Emory oak. On the basis of studies with other oaks, we hypothesized that acorn size is positively correlated with Emory oak germination, emergence, and seedling size.

In the field, differences in soil texture may also affect acorn germination and emergence and thus contribute to observed patterns of Emory oak seedling recruitment. Distributions of soil particle size under tree canopies are "gravelly sandy clay loams," whereas soils in adjacent grasslands range from "gravelly sandy loams" to "sandy loams" (Weltzin unpubl. data³). In addition, tree canopies may ameliorate understory microclimatic conditions by altering light and precipitation distribution or attenuating temperature extremes (Haworth and McPherson 1995). On the basis of observations of Weltzin and McPherson (1994, 1995) that Emory oak seedlings are most abundant under Emory oak tree canopies and absent from adjacent grasslands, we hypothesized that emergence of Emory oak would be greater in understory soil and understory microclimatic conditions than in grassland soil and grassland microclimatic conditions.

³Unpublished data on file, University of Arizona, School of Renewable Natural Resources, Tucson, Arizona.

Methods

Acorns were collected when ripe in July and August 1995 from at least 20 trees. Acorns were visually examined for insects and pathological infestation and sorted by flotation. Acorns that floated or had visible insect damage were discarded (sensu Nyandiga and McPherson 1992). All germination trials were conducted in petri dishes in a growth chamber under the following conditions: 12-hour day, 30 °C daytime temperature, and 20 °C nighttime temperature (as per Bonner 1988). Acorns with radicles that exceeded 1 mm were considered germinated. All germination trials began in early July 1995 and continued for 30 days after the last acorn germinated. Percent germination was calculated on the basis of the total number of acorns used in each trial.

Data were tested for normality with the Shapiro-Wilk *W*-statistic (Shapiro and Wilk 1965). Non-normal data were transformed or ranked (Conover and Iman 1981) before analysis of variance with general linear models. Data were tested for homogeneity of variances with Hartley's test (1950). Main effects and interactions were considered significant at $P < 0.05$; means were separated with Fisher's LSD (Least Significant Difference) mean separation test (Sokal and Rohlf 1981).

Post-Collection Processing and Storage Trial

This study employed a completely randomized design in a factorial arrangement with two factors: acorn treatment (cups left on acorns throughout germination trial, cups removed upon harvest, and cups removed after storage but before

germination trial) and storage time (0, 7, 14, 21, 28, and 35 days). Stored acorns were kept in moist sand at 2 °C (Young and Young 1992).

Acorn Size Trial

Acorns were separated into three distinct size classes by mass: large (>0.9 g), medium (0.6-0.8 g), and small (<0.5 g). Fifty acorns were randomly selected from each size class and were tested for viability with tetrazolium chloride, which stains respiring tissue red (*sensu* Nyandiga and McPherson 1992). An acorn was classified as viable if more than 50 percent of the tissue was stained red. An additional 100 acorns in each size class were used to study germination, emergence, and seedling size.

The time to germination was recorded for each individual acorn. Germinated acorns were transferred to pots filled with silica sand within 48 hours of germination. Acorns were buried 1 cm below the surface of the sand. Pots were retained in the growth chamber and monitored for shoot emergence; the time to emergence was recorded. For this trial, emergence is the number of acorns with shoots that emerged out of the number of acorns that germinated. Thirty-five days after germination, seedlings were destructively harvested, and above- and belowground dry-weight biomass (excluding the acorn) was determined.

Soil Type and Microclimate Trial

This study consisted of two experiments conducted simultaneously in the greenhouse and in the field. For both experiments we used field soil collected from lower Garden Canyon (31° 29' N, 110° 20' W), Fort Huachuca Military Reservation in southeastern Arizona. Haworth and McPherson (1995) provide a detailed site description. At Garden Canyon, we placed 0.5-m² plots under five randomly selected mature Emory oak trees, and in five randomly selected locations in semi-desert grassland below lower treeline. Plots under canopies were located on the north side of the tree bole between the bole and the canopy edge. At each plot, we filled 20 1-liter pots with soil from the top 20 cm of the soil profile ($n = 200$ pots). Half of the pots from each plot were retained in the field, and half were transported to a greenhouse in Tucson, Arizona. In the field, pots were redistributed under the constraint that each plot contained one pot from each of the 10 plots. Pots were buried such that the soil surface within the pot was level with the surrounding soil. Five acorns were planted 1 cm below the soil surface in each pot. Each plot was covered with 5-mm wire mesh to exclude vertebrates. Pots were weeded throughout the entire experiment. Initially, pots were not watered. However, since no emergence was observed for 3 weeks after planting, a second set of acorns was planted. Thereafter, pots were watered and monitored weekly for 3 and 10 weeks, respectively. For both experiments, percent emergence was calculated on the basis of the total number of acorns planted.

In the greenhouse, the pots with understory and grassland soil were arranged in a completely randomized design, and five acorns were planted into each pot. Pots were watered and monitored for emergence three times/week for 8 weeks. Emergence data were analyzed with Student's t-test on ranked data.

Results

Post-Collection Processing and Storage

Data were normally distributed with equal variances. A two-way interaction between acorn treatment and storage duration precluded simple consideration of main effects. Therefore, interpretation is based on interaction means.

Within storage-duration treatment, timing of acorn cup removal did not affect germination. After 7 and 35 days of storage, acorns without cups had

higher germination (53 and 78 percent) than acorns with cups intact (10 and 20 percent), respectively. Presence of acorn cups did not affect germination during other storage periods (47 percent).

Within acorn cup treatment, there were no consistent patterns of germination with respect to storage period. Acorns without cups (i.e., cups removed either before or after storage) had higher germination after storing for 35 days (78 percent) compared to storing for 28 days (43 percent), and germination following other storage times was intermediate (54 percent). In contrast, acorns stored and germinated with cups intact had higher germination after 0, 21, and 28 days of storage (42 percent) than after 7 days (10 percent), and germination associated with other storage times was intermediate (22 percent).

Acorn Size

Viability and germination did not differ between acorns in the large and medium size classes (table 1). However, viability and germination of acorns in the small size class was less than either of the larger size classes. Emergence of germinated acorns was nearly 100 percent, and did not differ between size classes. The larger the acorn, the greater the total (e.g., shoot and root) biomass produced. Mean time to germination (12 days) and emergence (19 days) did not differ between size classes.

Table 1—Effects of *Quercus emoryi* acorn size on mean viability, germination, emergence, and seedling size

Attribute	Large (>0.9 g)	Medium (0.6-0.8 g)	Small (<0.5 g)
Viability (pct)	100 a ¹	96 a	90 b
Germination rate (days)	11 a	13 a	11 a
Germination (pct)	27 a	20 a	11 b
Emergence rate (days)	19 a	21 a	19 a
Emergence (pct)	96 a	95 a	100 a
Root and shoot mass (g)	48 a	35 b	21 c

¹Within rows, means with the same letter do not differ ($P > 0.05$) according to Fisher's LSD test.

Soil Type and Microclimate

Cumulative seedling emergence in the greenhouse did not differ between understory and grassland soils (9 percent). Similarly, under field conditions, main and interactive effects of soil source and microclimatic conditions did not affect cumulative emergence (26 percent).

Discussion

Removal of acorn cups increased germination of *Quercus emoryi* as much as 5-fold, and in no case reduced germination. On this basis, we reject the hypothesis that the presence of the acorn cup does not affect germination. We therefore recommend that acorn cups be removed during acorn processing. Acorn cups not only inhibit germination, but their presence interferes with the ability to float-test acorns to assess their density: acorns that sink in water have a greater probability of being viable than those that float (Hubbard 1995).

Timing of cup removal (i.e., before or after short-term storage) did not affect germination in our trials, indicating that managers or researchers can remove acorn cups any time before planting. The high variability expressed with germination trials on this species suggest there may be a number of factors

affecting an acorn's germination success (Nyandiga and McPherson 1992).

Viability, germination, and seedling size of *Q. emoryi* were positively correlated with acorn size, which is consistent with other *Quercus* species (e.g., Tecklin and McCreary 1991). These results support our hypothesis. To maximize germination and emergence, we recommend that managers and researchers select relatively large acorns for revegetation projects and experimental studies.

Results from greenhouse and field trials lead us to reject our hypotheses that emergence in understory soil and understory microclimatic conditions will exceed emergence in grassland soil and grassland microclimatic conditions. This suggests that factors other than soil or microclimate limit seedling emergence. However, supplemental watering in the field may have masked differences in emergence that otherwise may have resulted from variability in soil and microclimate. Reasons for low emergence in the greenhouse are unknown. To better assess inter-annual effects of seasonal temperature and precipitation regimes on seedling emergence, this study will be repeated in 1996.

Results from these studies suggest that germination and emergence are not critical bottlenecks to oak distribution. Therefore, other aspects of recruitment may exert primary control over observed patterns of oak seedling distribution (Weltzin and McPherson 1994, 1995). Hubbard (1995) suggested that there is sufficient dispersal of acorns into adjacent grasslands to facilitate downslope movement of lower treeline. Results from these studies and preliminary data from other field and greenhouse trials (Germaine 1997, Weltzin unpubl. data³) suggest that amount and timing of precipitation exert important constraints on seedling emergence. For example, emergence of *Q. emoryi* at a southern Arizona field site was 25-45 times greater in watered plots than in unwatered plots (Germaine 1997).

Many ecological processes, including oak recruitment, are episodic. Recruitment of *Q. emoryi* appears to coincide with periods of above-average summer precipitation (McClaran and McPherson 1995). Consequently, future research should involve long-term monitoring of experimental treatments in order to better assess inter-annual variation in precipitation and recruitment.

Conclusions

Our investigations of different factors affecting germination and emergence revealed that regardless of the timing of acorn cup removal (e.g. before or after storage), removing the acorn cup increased germination up to 5-fold. Germination did not decline between 0 and 35 days of storage. Viability, germination, and seedling size were positively correlated with acorn size, but emergence and time to germination and emergence did not differ between size classes. Seedling emergence was not affected by soil source or microclimate. Therefore, given adequate soil moisture, germination and emergence are not bottlenecks limiting Emory oak distribution.

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