EFFECTS OF THE FOREST FLOOR AND ACORN PLACEMENT ON ESTABLISHMENT AND EARLY DEVELOPMENT OF WATER OAK SEEDLINGS[1]

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Abstract—Effects of the forest floor (0, 10, 20, 30, 40, and 50 Mg/ha) and acorn placement (buried 1.5 cm below the soil surface, pressed into the soil surface, and placed within the forest floor) on establishment and early development of water oak (*Quercus nigra* L.) seedlings were tested in a 6 x 3 factorial study in southeastern Arkansas. Increasing forest floor weight increased the number of seedlings established, but placing acorns within the forest floor drastically reduced establishment. Increasing forest floor weight significantly increased seedling height and root-collar diameter. When a forest floor was present, seedlings were much larger than those without a forest floor. Seedling developmental stage was also influenced by forest floor weight and acorn placement. At the termination of the study, seedlings with forest floors of 10 and 20 Mg/ha had more growth flushes than those without a forest floor and those with the heaviest forest floor. Root-collar diameter was significantly related to the dry weight of herbaceous plants and forest floor weight (R^2 = 0.73). Results of the study show that the forest floor affects establishment of water oak seedlings directly by modifying the acorn's micro-environment, and indirectly by suppressing the growth of herbaceous vegetation.

INTRODUCTION

The forest floor consists of shed and dead plant materials in various decomposition stages on the soil surface, and it is a distinctive feature of forest ecosystems. Since it affects the micro-environment of seeds, the forest floor has a pronounced effect on germination and early establishment of many species. The forest floor usually suppresses the establishment of small-seeded species (Koroleff 1954), but the forest floor may favor establishment of large-seeded species, such as the oaks. For example, Barrett (1931) reported that establishment of chestnut oak (*Quercus prinus* L.) seedlings maximized at a litter depth of 2.5 cm. Forest litter also indirectly affects seedling establishment by suppressing competing herbaceous plants (Facelli 1994, Yeiser 1994, Shelton 1995). The influence of the forest floor may be mitigated by animals which bury acorns (Deen and Hodges 1991, Thorn and Tzilkowski 1991). Nyandiga and McPherson (1992) reported greater germination of emory oak (*Q. emoryi* Torr.) and Arizona white oak (*Q. arizonica* Sarg.) acorns buried at a depth of 7.5 cm or deeper than acorns placed on the soil surface and covered with litter. Johnson and Krinard (1985) also reported the best seedling establishment for acorns of Nuttall (*Q. nuttallii* Palmer) and water (*Q. nigra* L.) oaks planted at a depth of 5.0 cm in a Sharkey clay soil. However, burying acorns in soil does not always produce better germination and establishment. Lockhart and others (1995) found reduced germination of buried white oak (*Q. alba* L.) acorns when protected from predation. The mixed results of acorn placement on germination and establishment reveal a complex interaction of various environmental conditions, including predation from animals.

Water oak is a widespread and commercially important species that occurs on a wide range of soils (Vozzo 1990). Some evidence indicates that establishment of water oak is not as dependent on advanced reproduction as other oak species (Loewenstein and Golden 1995). Because of this, acorn germination and early seedling establishment may be important to the regeneration of water oak, which has relatively small acorns. Since the establishment of small-seeded species can be negatively affected by the forest floor, we designed a study to evaluate the effects of forest floor weight and acorn placement on establishment, early growth, and development of water oak seedlings in southeastern Arkansas.

METHODS

The study was conducted in the University Forest (91° 50' W and 33° 37' N) of the School of Forest Resources, University of Arkansas at Monticello in Drew County, Arkansas. The study site is in the West Gulf Coastal Plain, and the soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludults). The native vegetation of the site was mixed pines and hardwood. Annual precipitation averages 1337 mm with most occurring in the winter and early spring.

The study used a 6 x 3 factorial split-plot design with a completely randomized block layout. Forest floor was the whole unit, while acorn placement was the subunit. The six forest floor weights were: 0, 10, 20, 30, 40, and 50 Mg/ha. The three acorn placements were: (1) buried 1.5 cm below the soil surface and the designated forest floor added, (2) pressed into the soil surface to the acorns horizontal centerline and covered with the designated forest floor, and (3) placed on the fermentation layer of the forest floor and covered by litter layer. The fermentation layer was material that had undergone decomposition, while the litter layer was freshly deposited material. When there was no forest floor, acorn placement within the forest floor was not possible; the study was, therefore, incomplete. Four blocks were used, yielding a total of 24 main plots and 68 subplots. A main plot occupied 0.22 m^2, and a subplot 0.073 m^2 with dimensions of 26 x 28 cm. Forest floor materials were collected from a 75-year-old mixed, upland-oak stand by litter and fermentation layers to facilitate reconstruction. The forest floor in the stand averaged 12 Mg/ha with 31 percent in the

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litter layer. Bulk materials were oven-dried at 50 °C. During bulk drying, a number of 100-g samples were collected and oven-dried at 105 °C to determine the residual moisture content of the bulk material, and adjustments were made during installation for corresponding treatment level weight.

The study was installed on January 12, 1994. The forest floor was reconstructed within wooden frames, establishing the same ratio of the litter and fermentation layers as observed in the stand where forest floor materials were collected. Water oak acorns were collected in Drew County, AR in November 1993 and float-tested before storing in a refrigerator at 4 °C until used in the present study. Six acorns were planted in each subplot. A removable screen covered each frame to keep out acorn predators.

Seedling ontogeny was evaluated weekly from May 21 to September 21, 1994 following the procedure of Hanson and others (1986). Developmental stages of seedlings were defined, and numerical values assigned to each stage for analysis purpose. At the termination of the study, height and root-collar diameter were measured. All aboveground herbaceous plants in each main plot were harvested and oven-dried at 105° C for 24 hours before weighing.

Height, root-collar diameter, and seedling development were analyzed by General Linear Models (GLM) of SAS (SAS Institute Inc. 1990). Means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test at $p = 0.05$. When factors interacted significantly, a variable was created for each forest floor-acorn placement combination, and then these means were separated as if they were a one-way classification (Littell and others 1991). Because of the very low establishment of seedlings for acorn placement within the forest floor, that treatment was not included in the statistical analyses of seedling height, diameter, and developmental stage. Regression was also used to determine the effect of herbaceous plant dry weight and forest floor weight on seedling height and diameter.

RESULTS

The forest floor did not significantly affect the establishment of water oak seedlings ($p = 0.53$), while acorn placement strongly affected seedling establishment ($p = 0.0001$). In addition, the forest floor significantly interacted with acorn placement ($p = 0.01$). Forest floor placement resulted in the lowest seedling establishment of all placement treatments, averaging only 12 percent. In contrast, the average establishment was 85 percent for the soil surface-placement and 81 percent for the buried placement (fig. 1). The significant interaction between forest floor and acorn placement was due to the increased seedling establishment with the increasing forest floor weight for the forest-floor placement. When a forest floor of 50 Mg/ha was present, establishment was 37 percent compared to 0 percent with a forest floor of 10 Mg/ha. For acorns pressed into the soil surface, the lowest establishment occurred when no forest floor was present, but increasing the forest-floor weight from 0 to 50 Mg/ha had no substantial effect on establishment. Buried acorns also had the lowest establishment when no forest floor was present. Establishment of buried acorns peaked at 96 percent for a forest floor of 10 Mg/ha, although no statistical difference was detected among the forest-floor treatments.

Seedling height and root-collar diameter (fig. 2) were significantly affected by forest floor ($p = 0.004$ and 0.001, respectively), but acorn placement did not significantly affect either height or diameter ($p = 0.15$ and 0.11, respectively). The interaction between the forest floor and acorn placement was not significant ($p = 0.42$ and 0.23, respectively). Mean height and root-collar diameter were lowest when no forest floor was present, and they were greatest for forest floor weights of 10 and 20 Mg/ha (fig. 2).

The forest floor significantly affected the developmental stage of seedlings ($p = 0.002$), while the effect of acorn placement and the interaction was not significant ($p = 0.32$ and 0.39, respectively). At the termination of the study, seedlings with a forest floor present were at fourth flush appearing or beyond, while seedlings with no forest floor were at the lag period for the third flush. The most highly developed seedlings were for the 10 and 20 Mg/ha forest floors, where the mean seedling was in the lag period of the fourth flush. However, increasing forest floor weight above 20 Mg/ha retarded seedling development (fig. 3).

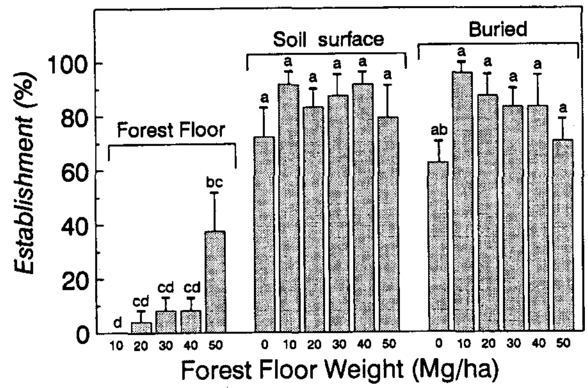

Figure 1—Effects of forest floor weights and acorn placement on the establishment of water oak seedlings in southeastern Arkansas. Standard errors are represented by the vertical lines.

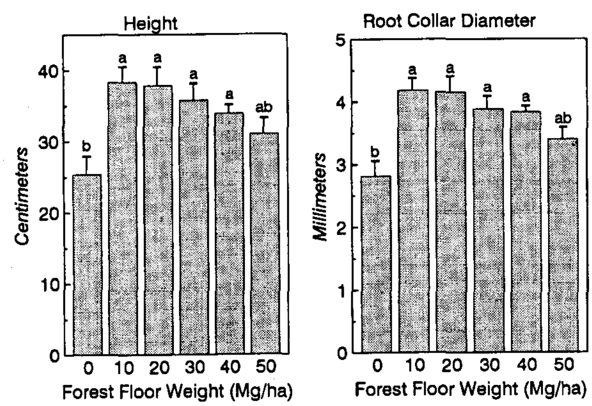

Figure 2—Effects of forest floor weights on the height and root-collar diameter of water oak seedlings at the termination of the study. Means are for the buried and soil surface placements only—the forest floor placement was not included due to low seedling establishment. Bars with the same letters are not significantly different ($p = 0.05$), and standard errors are represented by the vertical lines.

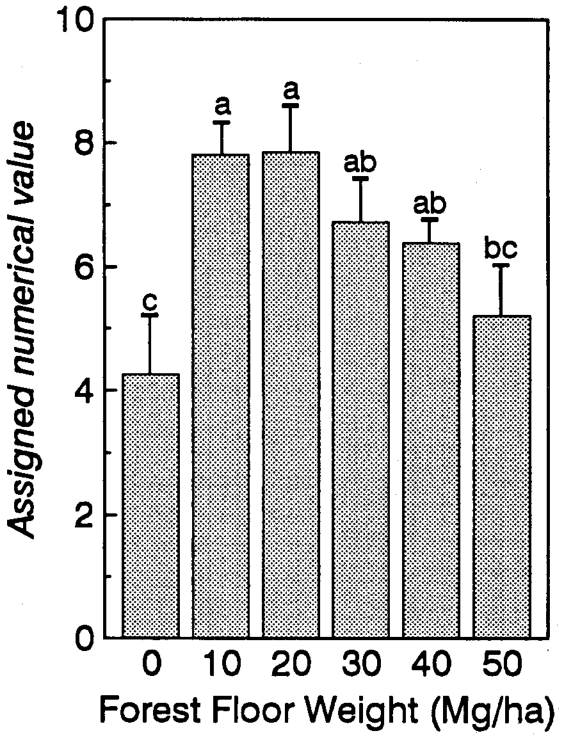

Figure 3—Effects of forest floor weights on the developmental stage of water oak seedlings at the termination of the study. Means are for the buried and soil-surface acorn placements only—the forest-floor placement was not included due to low seedling establishment. Bars with the same letters are not significantly different (p = 0.05), and standard errors are represented by the vertical lines. Assigned numbers represent the following stages: 4 = lag period third flush, 5 = fourth flush appearing, 6 = stem elongation fourth flush, 7 = leaf expansion fourth flush, 8 = lag period fourth flush, and 9 = fifth flush appearing.

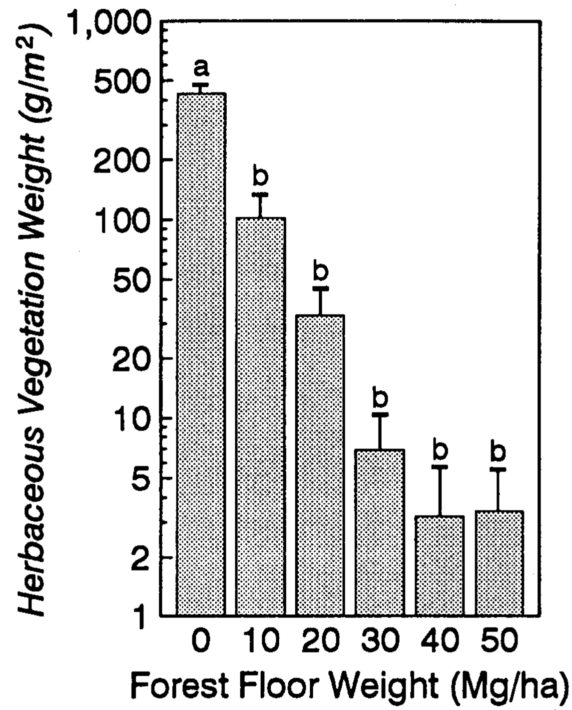

Figure 4—Effects of forest floor weights on the amount of herbaceous vegetation at the termination of the study. Bars with the same letters are not significantly different (p = 0.05), and standard errors are represented by the vertical lines. Note that the scale for herbaceous weight is logarithmic.

Herbaceous plants were strongly suppressed by the forest floor ($p = 0.0001$). When no forest floor was present, the dry weight of herbaceous vegetation averaged 430 g/m^2. The dry weight was reduced to about 7 g/m^2 for a forest floor of 30 Mg/ha (fig. 4).

Root-collar diameter (D in mm) was exponentially related with forest floor weight (F in Mg/ha) and the dry weight of herbaceous plants (H in g/m^2) as shown in the following equation:

$$\ln D = 1.60 - 0.00736\,F - 0.00131\,H \qquad (1)$$

This equation had a coefficient of determination (R^2) of 0.73. Both independent variables were significant ($p = 0.0002$ and 0.0001, respectively). Applying equation (1), the predicted root-collar diameter was 2.8 mm for a 0 Mg/ha forest floor with 430 g/m^2 of herbaceous plants. The predicted diameter increased to 4.0 mm when the forest floor was increased to 10 Mg/ha and herbaceous plants reduced to 100 g/m^2. Seedling height was not as closely related to forest floor amount and herbaceous plant weight as was root-collar diameter ($R^2 = 0.42$).

DISCUSSION

A wider range of the forest floor weights was tested in this study than forest floors typically found under field conditions, especially the 40 and 50 Mg/ha treatments. This was done to determine the effects of extreme forest floor conditions on acorn germination and seedling establishment. During forest succession on uplands in the Upper Coastal Plain, Switzer and others (1979) found that forest floor weights maximized at a mean of 21 Mg/ha in 65-year-old pine stands and then declined to 14 Mg/ha as hardwoods became dominant. These average forest floors were close to the 10 to 20 Mg/ha treatments of our study. Switzer and others (1979) also noted that considerable forest floor variation may occur due to local variation in topography, drainage, and site features that tend to accumulate litter.

Results of this study indicate that it is very important for acorns to be in contact with mineral soil for high rates of seedling establishment for water oak. Pressing water oak acorns into the soil surface or burying acorns increased seedling establishment, height, root-collar diameter, and developmental stage. A forest floor of 10 or 20 Mg/ha also improved the establishment, growth, and development of seedlings. For the buried and soil-surface placements, seedling establishment increased from 67 percent without a forest floor to 94 percent with a forest floor of 10 Mg/ha. The forest floor apparently improved the moisture relationships for acorns buried in the soil or on the soil surface. The research site for this study was a small forest opening, and exposure to full sunlight was extensive. Soil moisture may have been limiting during the germination of acorns and the subsequent growth of seedlings. In studying the effects of soil surface topography and litter cover on musk thistle (*Carduus nutans* L.), Hamrick and Lee (1987) indicated that optimum germination, survival, and growth occurred in treatments that reduced evaporation. Johnson and Krinard (1985) also pointed out that better germination and establishment of Nuttall oak was partially due to improved soil moisture for buried acorns.

Acorn placement within the forest floor drastically reduced seedling establishment, which averaged only 12 percent. However, seedling establishment for acorns placed within the forest floor tended to increase for the heavier weights. Establishment was 37 percent for a forest floor of 50 Mg/ha. Water oak acorns or their radicles apparently have a low ability to absorb moisture from forest floor material. Acorns either died due to desiccation while dormant, or the radicles died while attempting to penetrate the fermentation layer and reach the soil. The heavier forest floors apparently provided protection to moderate desiccation and increased seedling establishment.

The acorn size and germination characteristics may affect the establishment of seedlings from acorns placed within the forest floor. Within a species, acorn size has been found to be positively related to the establishment and growth of seedlings for blue oak (*Q. douglasii* Hook. & Arn.) by Tecklin and McCreary (1991), and for blue oak, valley oak (*Q. lobata* Nee), and coast live oak (*Q. agrifolia* Nee) by Matsuda and McBride (1986). Lockhart and others (1995) found that white oak acorns, placed within similar forest floors as those of this study, germinated and established equally well as the acorns in contact with the soil surface. Burying white oak acorns, however, reduced germination. White oak acorns are very large and germinate soon after falling to the ground (Rogers 1990). The large acorns may provide more energy to support radicle growth into the soil. In addition, radicles reaching the soil may prevent the desiccation of white oak acorns during the winter. We have also noted that the radicles of white oak are very robust when compared to the radicles of water oak, which may have difficulty penetrating the physical barrier presented by the forest floor.

The forest floor strongly affected the establishment and growth of herbaceous vegetation in the study area. Increasing forest-floor weight from 0 to 30 Mg/ha reduced the amount of herbaceous vegetation by over 60 fold. Clearly, this herbaceous vegetation competed with water oak seedlings for moisture, resulting in smaller seedlings when no forest floor was present. A similar improvement in the growth of planted and natural loblolly pine (*Pinus taeda* L.) seedlings has also been attributed to the suppression of competing herbaceous vegetation by the forest floor (Yeiser 1994, Shelton 1995). In contrast to this beneficial effect, forest floors over 20 Mg/ha reduced the height, root-collar diameter, and developmental stage of seedlings in the present study. Although the causal mechanism is not clear from our results, a heavy forest floor may reduce growth by adversely affecting aeration or temperature within the acorn's micro-environment. For example, the insulating effect of the forest floor may have slowed soil warming during the spring, thereby retarding acorn germination. Under field conditions, the forest floor may also indirectly benefit oak establishment by protecting acorns from predation. For example, Myster and Pichett (1993) reported that forest litter reduced seed predation by animals for six tree species, including northern red oak (*Q. rubra* L.).

Results of this study allow us to make the following conclusions. First, water oak acorns need to be in contact with mineral soil for high rates of seedling establishment. Acorns that were pressed into the soil surface to their centerline yielded very similar results to acorns that were buried at a depth of 1.5 cm. Acorns that were placed within the forest floor had low seedling establishment, apparently due to desiccation during dormancy or germination. Second, forest- floor weights over 20 Mg/ha suppressed the growth and development of water oak seedlings developing from acorns in contact with the mineral soil, possibly by adversely affecting aeration or temperature. Third, the forest floor strongly suppressed the amount of herbaceous vegetation, thereby reducing competition levels for water oak seedlings. Fourth, optimum establishment, growth, and development of water oak seedlings occurred at moderate forest floor weights (10 to 20 Mg/ha), which are close to the average conditions found in hardwood stands in the southeastern United States.

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