Acorn Production on the Missouri Ozark Forest Ecosystem Project Study Sites: Pre-treatment Data

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Abstract.—In the pre-treatment phase of a study to determine if even- and uneven-aged forest management affects the production of acorns on the Missouri Forest Ecosystem Project (MOFEP) study sites, acorn production was measured on the nine study sites by randomly placing from 2 to 6 plots in each of four ecological land type (ELT) groupings (N=130 plots). A split-plot multivariate analysis of variance revealed that the production of sound, mature acorns varied significantly among years, blocks, and ELT's. In addition, a significant year by "treatment" effect was observed. When years were combined to examine between subjects effects, ELT was shown to have a significant effect on acorn production. ELT also affected average sound, mature acorn production per 1,000 m^2 of oak canopy area with ridgetops being the most productive. Given the variability observed in acorn production during the 3 years of this study, it is clear that only very long term data on acorn production will provide the information needed to meet the study's objectives.

Oak mast is a very important source of fall and winter food for many species of wildlife (Dickson 1990, Goodrum *et al.* 1971, Perry 1991, Rogers *et al.* 1990, Smith and Scarlett 1987). Poor mast years have been shown to result in lowered reproductive success and/or reduced numbers of squirrels (*Sciurus* spp.) (Barkalow *et al.* 1970, Nixon and McClain 1969), white-tailed deer (*Odocoileus virginianus*) (Rogers *et al.* 1990, Wentworth *et al.* 1992), black bears (*Ursus americanus*) (Rogers 1976), and red-headed woodpeckers (*Melanerpes erythrocephlus*) (Smith and Scarlett 1987). Acorns are also important in the regeneration of oak trees (Cecich 1992). Because of the importance of mast in the ecology of the Ozark forest, a study is being conducted to determine if and how even- and uneven-aged forest management affect the production of acorns on the MOFEP study sites. This paper present 3 years of acorn production data from the pre-treatment phase of the MOFEP experiment (Sheriff and He 1997).

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METHODS

Acorn Collection Methods

Methods of hard mast collection were modified from Myers (1979) and Christisen and Kearby (1984) and are similar to those being used in another ongoing study of hard mast production in the Missouri Ozarks that began in 1989 (Schroeder and Vangilder 1997). Because of the extreme variability of acorn production among individual trees, species, and years (Christisen and Kearby 1984), and because of the impracticality of sampling acorns from individual trees in a closed canopy forest, I chose to determine the number of acorns falling to the ground on a plot of land rather than the number of acorns falling to the ground under an individual tree. In addition, repeated measures of the acorn production of an individual tree through the entire course of the MOFEP experiment (Sheriff and He 1997) would not be possible because of natural tree mortality and tree mortality due to treatment. Therefore, a plot of land that will remain intact throughout the entire course of the experiment was the correct sampling unit. A 4 X 5 grid of 20 traps was systematically placed in a 7.7 X 8.7 m spacing to sample acorn production in plots. To estimate acorn production, each plot was 38.5 X 53 m in size (2,002

m^2). Each cone-shaped trap was 0.73 m in diameter and constructed from 6-mil plastic. Traps were suspended above ground on three 1.52-m pieces of 0.95-cm reinforcement rod. The 20 traps sampled 8.37 m^2 of the plot.

From 1993 through 1995, mast was collected weekly from each plot beginning in August and ending when no mast was collected from any plot (January or February). Hard mast from each trap was placed in small paper grocery sacks and labeled with the site, plot, and trap number. Weekly collections were air-dried by hanging sacks on clotheslines indoors. When air dry, the nuts from each sack were identified to species and weighed, and their maturity class was determined (Christisen and Kearby 1984). Five maturity classes were identified with classes 4 and 5 considered mature (Christisen and Kearby 1984). Soundness of each nut was determined by cutting the nut open to determine whether any of the fruit remained. Nuts in which more than half the fruit remained were considered sound.

Placement of Acorn Plots

I chose to use stratified random sampling to decide where to place the acorn plots. Thirteen different ecological land types (Miller 1981) occurred under the original ELT designations. However, three ELT's made up almost 90 percent of the total land area of the sites. South and west slopes (ELT 17), north and east slopes (ELT 18), and ridgetops (ELT 11) were the most frequent ELT's. The next most common ELT's were broad ridges (ELT 15) and upland waterways (ELT 5). Thus, each of the nine MOFEP sites was divided into four ELT groupings: ridgetops (ELT's 11 and 15), south and west slopes (ELT 17), north and east slopes (ELT 18), and a group containing all the other ELT's (this group is subsequently called "other"). Each site was originally targeted to receive at least 12 plots. Plots were randomly assigned to each ELT grouping roughly in proportion to the area that each of the groups made up on each of the sites. Under the original ELT designation, one site (Site 1) had only the three major ELT groups (no "other" ELT's). On Site 1, I chose to establish two plots in areas that upon field examination were known to be in one of the "other" ELT's even though the "other" ELT had not been designated as such. As a result of this sampling scheme, 130 plots were placed on the nine study sites (fig. 1). Because upland waterways (ELT 5) (Miller 1981) dominated the "other" ELT group, most acorn plots in the "other" ELT group were actually on upland waterways (ELT 5).

Measurement of Trees on Plots

Each tree greater than or equal to 11.4 cm diameter at breast height (d.b.h.) was measured, identified to species, and marked with a uniquely numbered metal tag. The canopy position and condition of each tree were also recorded. In addition, the distance and azimuth of each tree to the center of the plot was recorded so that a map of the trees on each plot could be made. For tree measurement, the outside edge of the plot was considered to be a distance of 9.144 m out from the outside line of traps. This distance was chosen because a preliminary analysis of the data from the 648 permanent plots (Brookshire *et al.* 1997) indicated that only 22 of 9,664 trees in these plots had crown radii greater than 9.144 m. Plot size for the purpose of tree measurement was 42.118 m by 53.818 m or 2,266.7 m^2. The above measurements were taken from January-March 1995. The crown diameter of each marked tree was measured parallel to the long and short axes of the plot from February to April 1996. These two measurements were averaged and the average was divided by 2 to determine the average radius of the crown of each tree. Scientific nomenclature for trees follow Settergren and McDermott (1974).

Statistical Analysis

Analysis of Variance Approach

The number of sound, mature acorns per plot for each of the 3 years of the study was used as the dependent variable in a multivariate analysis of variance. Because the number of acorns per plot was "count" data, the data were transformed using a square root transformation ($\sqrt{(x+1)}$) (Snedecor and Cochran 1967: 325). The design was a repeated measures (year), split-plot (ELT) design (MODEL 3, Sheriff and He 1997). For analysis of oak tree d.b.h., average canopy area of oaks, and average sound, mature acorn production per 1,000 m^2 of oak crown area, a split-plot repeated measures design was used (MODEL 2, Sheriff and He 1997). Although there were 130 acorn plots, there were only three blocks, three treatments, and four ELT's; therefore, the sample size for each year for sound, mature acorns per plot

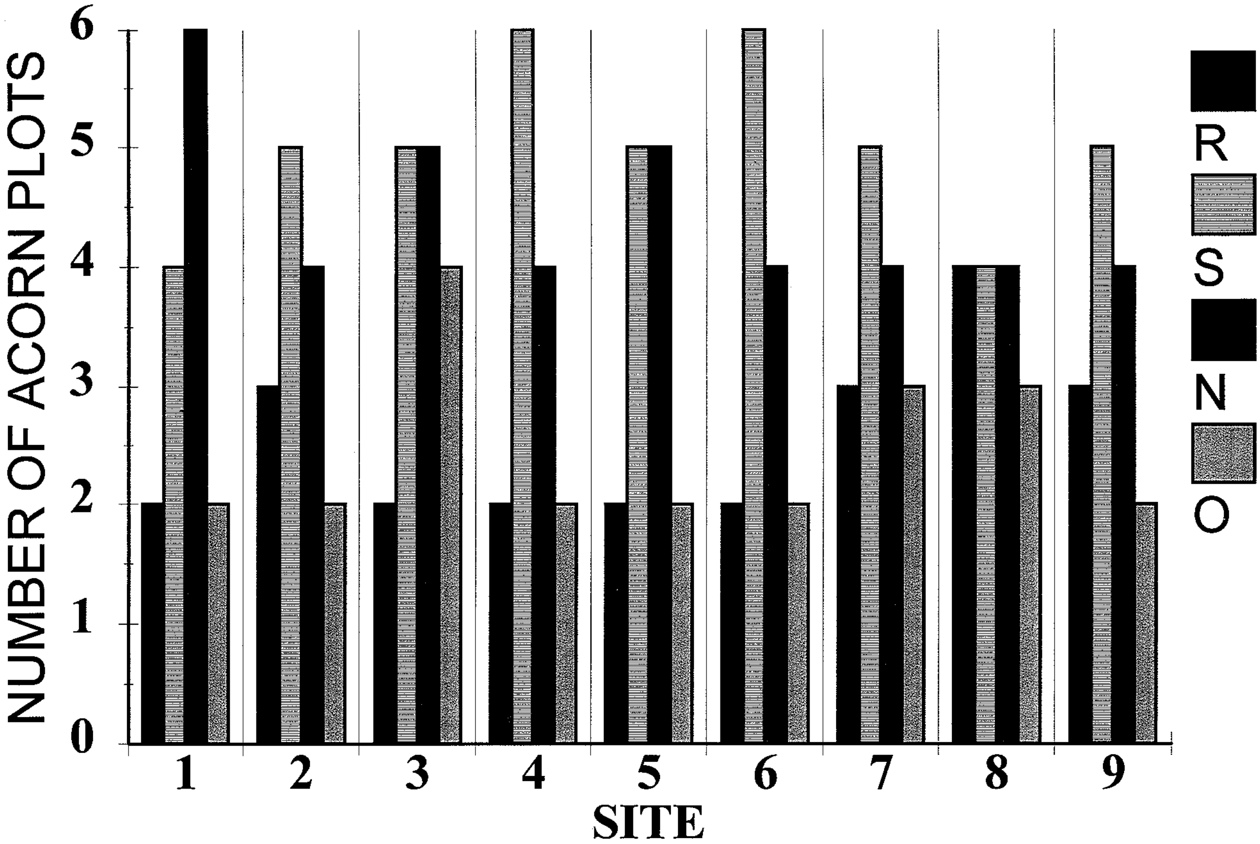

Figure 1.—*Number of acorn plots placed on each MOFEP study site by ELT grouping. R=ridgetop, S=south and west slope, N=north and east slope, and O="other."*

was 36. An average number of acorns per plot for the plots that belonged to each of the 36 block, treatment, and ELT combinations was used in the multivariate analysis. A similar procedure was used for oak tree d.b.h. and average canopy area of oak trees. For average sound, mature acorn production per 1,000 m^2 of oak crown area, sound, mature acorn production was averaged across the 3 years of the study for each plot. This average for each plot was then divided by the total crown area of oaks (m^2) in that plot divided by 1,000. Pairwise comparisons of oak tree d.b.h., average canopy area of oak trees, and average sound, mature acorn production per 1,000 m^2 of oak crown area were made with Fisher's Protected Least Significant Difference test (Huitema 1980: 82-86). The significance level for all statistical tests was set at α=0.1.

Sampling Approach

For each year, the total number of sound, mature acorns produced was estimated for each of the nine MOFEP sites by summing the four separate estimates for each strata. Similarly, for each year, the variance of each estimate for each site was also calculated by summing the four variance estimates for each strata (Cochran 1977: 89-96). Each estimate of the total production of sound, mature acorns per site and the lower and upper bounds of the 95 percent confidence interval of the estimate were then converted to estimates of sound, mature acorns per hectare by dividing the total estimate and the lower and upper bounds of the 95 percent confidence interval by the number of hectares in each site.

To determine whether stratification by ELT helped reduce the sampling variance of acorn production estimates, the percent gain in efficiency was calculated by comparing the variance of each estimate as calculated above with the variance of each estimate when calculated as if the sample had been a simple random sample (Cochran 1977: 136-138).

Acorns were also divided into two groups: those from red oak group trees and those from white oak group trees. Data were then examined by site, year, and species group to determine what proportion of the sound mature acorn production came from red oak group trees.

The proportion of sound, mature acorns of all mature acorns from each group that fell into traps was also determined for each site and year.

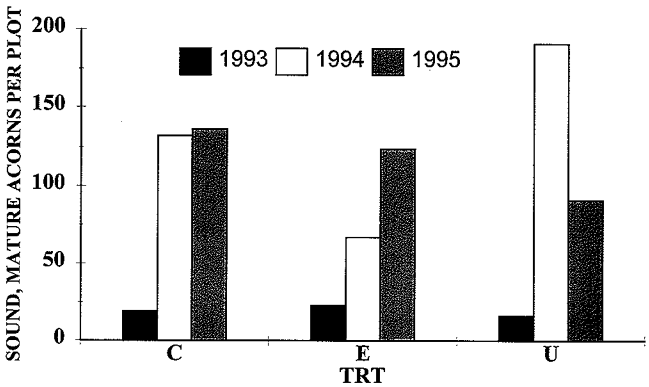

Figure 2.—*Number of sound, mature acorns per plot by year and treatment (trt) (C=control, E=even-aged, U=uneven-aged) on the MOFEP study sites.*

RESULTS

Analysis of Variance Approach

Acorns

A multivariate analysis of variance revealed a significant YEAR X TREATMENT interaction (P=0.0386) (table 1). In 1994, the number of sound, mature acorns per plot appeared differentially higher on sites designated to receive the uneven treatment when compared with the other year and treatment combinations (fig. 2). An alternative explanation for the YEAR X TREATMENT interaction is that the number of sound, mature acorns per plot was differentially lower on sites designated to receive the even-aged treatments. A significant YEAR X BLOCK X ELT interaction (P=0.0201) for the number of sound, mature acorns per plot was also detected (table 1). The number of sound, mature acorns per plot did not differ consistently across the year, block, and ELT combinations (fig. 3).

When between subjects effects were examined, a significant ELT effect was revealed (P=0.0001) (table 2). The mean number of sound, mature

Table 1.—*Multivariate analysis of variance table for a split-plot, repeated measures design with the dependent variables being the number of sound, mature acorns per plot (transformed by $\sqrt{(x+1)}$) for 1993, 1994, and 1995 and the independent variables being the fixed effects of BLOCK, TREATMENT, AND ELT. Pillai's trace was used as the multivariate test criterion. The numerator (Num DF) and denominator (Den DF) degrees of freedom are shown for each effect. The sample size is 36 (3 BLOCKS X 3 TREATMENTS X 4 ELTS). The YEAR X BLOCK X TREATMENT sum of squares and cross products (SSCP) matrix (ERROR A) was used to test the YEAR X BLOCK and YEAR X TREATMENT interaction SSCP matrices. The ERROR B SSCP matrix was used to test the remainder of the effects.*

Effect	Pillai's Trace	Num DF	Den DF	Pr>F
YEAR	282.12	2	11	0.0001
ERROR B				
YEAR X BLOCK	1.83	4	8	0.2172
YEAR X TREATMENT	4.27	4	8	0.0386
YEAR X BLOCK X TREATMENT (ERROR A)				
YEAR X ELT	2.56	6	24	0.0467
YEAR X BLOCK X ELT	2.66	12	24	0.0201
YEAR X TREATMENT X ELT	0.50	12	24	0.8930
ERROR B				

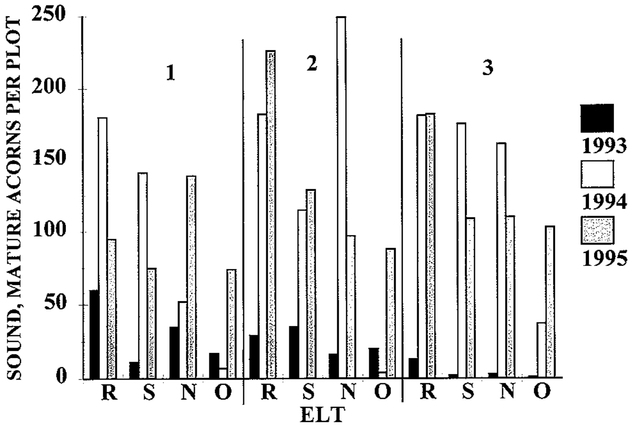

Figure 3.—*Number of sound, mature acorns per plot by year, block (1,2,3) and ELT grouping (R=ridgetop, S=south and west slope, N=north and east slope, and O="other") on the MOFEP study sites.*

acorns produced per plot was higher on ridgetops than any other ELT group (P≤0.0347) (table 3). South and west and north and east slopes did not differ in acorn production (P=0.6142), but both south and west and north and east slopes produced significantly more sound, mature acorns per plot than did the "other" ELT group (P≤0.0004) (table 3).

Trees

A total of 11,020 trees ≥ 11.4 cm d.b.h. were measured on the 130 acorn plots. The most frequent trees on the plots were white oak (*Quercus alba*) (28.2 percent), scarlet oak (*Quercus coccinea*) (16.5 percent), black oak (*Quercus velutina*) (15.4 percent), and shortleaf pine (*Pinus echinata*) (9.3 percent). Post oak (*Quercus stellata*) (5.5 percent) was the only other species of oak that made up more the 1 percent of the total individuals. Other species that made up more than 1 percent of the total trees were black hickory (*Carya texana*) (5.5 percent), mockernut hickory (*Carya tomentosa*) (5.2 percent), pignut hickory (*Carya glabra*) (5.2 percent), blackgum (*Nyssa sylvatica*) (1.7 percent), and flowering dogwood (*Cornus florida*) (1.3 percent).

A split-plot analysis of variance revealed no significant BLOCK or TREATMENT effects for mean d.b.h. of oak (*Quercus* spp.) trees ≥ 11.4 cm d.b.h. (table 4). However, the effect of ELT was significant (table 4). Mean d.b.h. of oak trees was significantly lower in the "other" ELT group than in the other three ELT groups (P≤0.0580) (fig. 4). Mean d.b.h. of oak trees on south and west slopes was lower than on ridgetops (P=0.0063) (fig. 4).

A split-plot analysis of variance revealed a significant BLOCK but no significant TREATMENT effect for mean canopy area of oak trees ≥ 11.4 cm d.b.h. (table 5). The mean canopy area in block 3 (Peck Ranch) was significantly higher (P < 0.0221) than in block 1 (fig. 5). The effect of ELT was also significant (table 5). Mean canopy area of oak trees was significantly

Table 2.—*Multivariate analysis of variance table for between subject effects for a split-plot, repeated measures design with the dependent variable being the sum of the number of sound, mature acorns per plot (transformed by $\sqrt{(x+1)}$) for 1993-1995 divided by the square root of 3 and the independent variables being the fixed effects of BLOCK, TREATMENT, AND ELT. The sample size is 36 (3 BLOCKS X 3 TREATMENTS X 4 ELTS). The BLOCK X TREATMENT effect (ERROR A) was used to test the BLOCK and TREATMENT effects. ERROR B was used to test the remainder of the effects.*

Effect	DF	Mean Square	F Value	Pr>F
BLOCK	2	14.07	1.07	0.4258
TREATMENT	2	15.94	1.21	0.3890
BLOCK X TREATMENT (ERROR A)	4	13.21		
ELT	3	141.55	21.20	0.0001
BLOCK X ELT	6	2.63	0.39	0.8689
TREATMENT X ELT	6	7.68	1.15	0.3925
ERROR B	12	6.68		

Table 3. *Means separation for the between subjects analysis of variance (see table 2) with the dependent variable being the sum of the number of sound, mature acorns per plot (transformed by $\sqrt{(x+1)}$) for 1993-1995 divided by the square root of 3 and the independent variables being the fixed effects of BLOCK, TREATMENT, AND ELT. The sample size is 36 (3 BLOCKS X 3 TREATMENTS X 4 ELTS). The means shown in this table were reconverted to the original scale by multiplying the transformed mean by $\sqrt{3}$, dividing the result by 3, then squaring this result, subtracting 1, and adding the error mean square (Snedecor and Cochran 1967: 327). The t-values and the associated Pr>t are based on the transformed data. The critical value for the Fisher's Protected Least Significant Difference at α=0.10 with 12 degrees of freedom is 1.782.*

ELT	Mean	t-value (Pr > |t|) of indicated comparison		
		S	N	O
Ridgetop	114	2.90 (0.0134)	2.38 (0.0347)	7.76 (0.0001)
South and West Slopes (S)	75		-0.52(0.6142)	4.86 (0.0004)
North and East Slopes (N)	82			5.38 (0.0002)
Other (O)	30			

Table 4.—*Analysis of variance table for a split-plot design with the dependent variable being the mean diameter at breast height (d.b.h.) of oak trees and the independent variables being the fixed effects of BLOCK, TREATMENT, AND ELT. The sample size is 36 (3 BLOCKS X 3 TREATMENTS X 4 ELTS). The BLOCK X TREATMENT effect (ERROR A) was used to test the BLOCK and TREATMENT effects. ERROR B was used to test the remainder of the effects.*

Effect	DF	Mean Square	F Value	Pr>F
BLOCK	2	7.05	3.75	0.1211
TREATMENT	2	0.39	0.21	0.8226
BLOCK X TREATMENT (ERROR A)	4	1.88		
ELT	3	5.69	10.63	0.0001
BLOCK X ELT	6	0.18	0.33	0.9083
TREATMENT X ELT	6	0.26	0.49	0.8067
ERROR B	12	0.54		

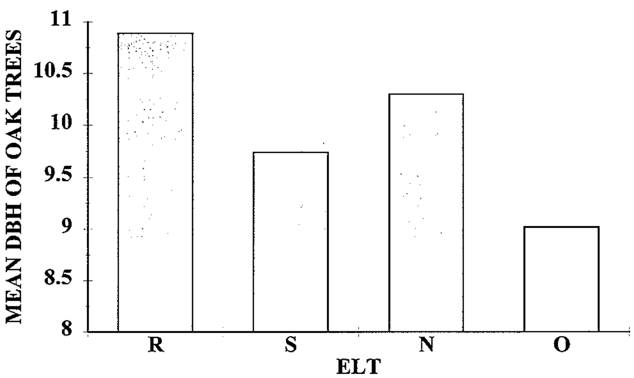

Figure 4.—*Mean diameter at breast height (d.b.h.) of oak trees greater than 11.4 cm (d.b.h.) by ELT grouping (R=ridgetop, S=south and west slope, N=north and east slope, and O="other") on the MOFEP study sites.*

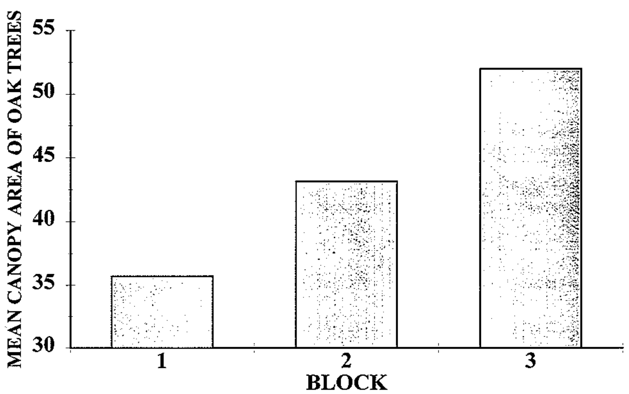

Figure 5.—*Mean canopy area of oak trees (m^2) by block on the MOFEP study sites.*

Table 5.—*Analysis of variance table for a split-plot design with the dependent variable being the mean canopy area of oak trees and the independent variables being the fixed effects of BLOCK, TREATMENT, AND ELT. The sample size is 36 (3 BLOCKS X 3 TREATMENTS X 4 ELTS). The BLOCK X TREATMENT effect (ERROR A) was used to test the BLOCK and TREATMENT effects. ERROR B was used to test the remainder of the effects.*

Effect	DF	Mean Square	F Value	Pr>F
BLOCK	2	796.24	6.62	0.0539
TREATMENT	2	66.91	0.56	0.6122
BLOCK X TREATMENT (ERROR A)	4	120.32		
ELT	3	194.55	7.52	0.0043
BLOCK X ELT	6	10.24	0.40	0.8680
TREATMENT X ELT	6	44.36	1.71	0.2008
ERROR B	12	25.87		

lower in the "other" ELT group than in the other three ELT groups ($P \leq 0.0581$) (fig. 6). Mean canopy area of oak trees on south and west slopes was lower than on ridgetops ($P=0.0590$) or north and east slopes ($P=0.0910$) (fig. 6).

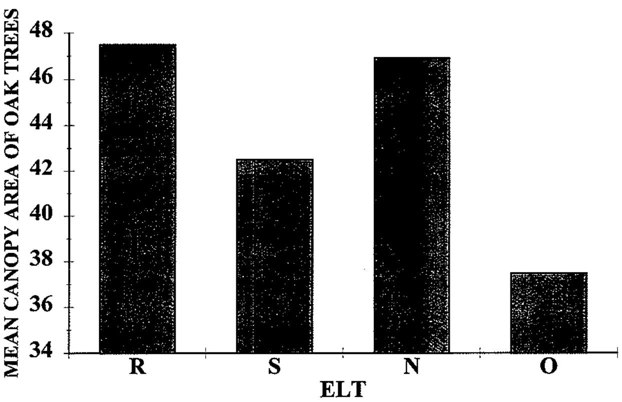

Figure 6.—*Mean canopy area of oak trees (m^2) by ELT grouping (R=ridgetop, S=south and west slope, N=north and east slope, and O="other") on the MOFEP study sites.*

Acorn Production per 1,000 m^2 of Oak Crown Area

A split-plot analysis of variance revealed no significant BLOCK or TREATMENT effects for average sound, mature acorn production per 1,000 m^2 of oak crown area (PCAN) (table 6). However, the effect of ELT on PCAN was significant (table 6). Means separation of PCAN by ELT revealed that even given equal amounts of total oak canopy area, ridgetops produced more sound, mature acorns than any of the other three ELT groups ($P \leq 0.0802$) and north and east slopes produced more sound, mature acorns than the "other" ELT group ($P < 0.0567$) (table 7).

Sampling Approach

Sound, mature acorn production (sound, mature acorns per hectare) ranged from 2,783 sound, mature acorns per hectare on site 8 in 1993 to 341,506 acorns per hectare on site 7 in 1994 (fig. 7). Acorn production in 1993 was lower than in 1994 or 1995. Average production across the nine sites was 23,280, 165,117, and 138,797 sound, mature acorns per hectare in 1993, 1994, and 1995, respectively.

The proportion that the half-width of the 95 percent confidence interval made up of the acorn production estimates for each year and site ranged from 0.24 to 1.23 (fig. 8). On eight of nine sites, the 95 percent confidence interval was wider in 1993 when acorn production estimates were lower (fig. 8).

The gain in efficiency (reduction in sampling variance) as the result of stratification by ELT ranged from -27.9 percent on site 2 in 1994 to 52.6 percent on site 6 in 1994 (fig. 9). In 1993 and 1994, seven and six sites, respectively, showed gains in efficiency. In 1995, only three of the nine sites showed gains in efficiency (fig. 9).

The proportion of sound, mature acorns that came from red oak group trees ranged from 0.23 in 1993 on site 5 to 0.99 on site 6 in 1994

Table 6.—*Analysis of variance table for a split-plot design with the dependent variable being the average sound, mature acorn production per 1,000 m² of oak canopy area (PCAN) and the independent variables being the fixed effects of BLOCK, TREATMENT, AND ELT. The sample size is 36 (3 BLOCKS X 3 TREATMENTS X 4 ELTS). The BLOCK X TREATMENT effect (ERROR A) was used to test the BLOCK and TREATMENT effects. ERROR B was used to test the remainder of the effects.*

Effect	DF	Mean Square	F Value	Pr>F
BLOCK	2	303.88	0.46	0.6620
TREATMENT	2	309.47	0.47	0.6575
BLOCK X TREATMENT (ERROR A)	4	663.39		
ELT	3	1213.12	5.43	0.0136
BLOCK X ELT	6	122.80	0.55	0.7616
TREATMENT X ELT	6	246.95	1.11	0.4136
ERROR B	12	223.37		

Table 7.—*Means from a split-plot analysis of variance for the effect of ELT on the average sound, mature acorn production per 1,000 m² of oak canopy area (PCAN). The critical value for the Fisher's Protected Least Significant Difference at α=0.10 with 12 degrees of freedom is 1.782.*

ELT	Mean PCAN	t-value (Pr > |T|) of indicated comparison S	N	O
Ridgetop	53.57	2.26(.0430)	1.91 (0.0802)	4.02 (0.0017)
South and West Slopes (S)	37.63		0.35 (0.7312)	1.76 (0.1043)
North and East Slopes (N)	40.11			2.11 (0.0567)
Other (O)	25.25			

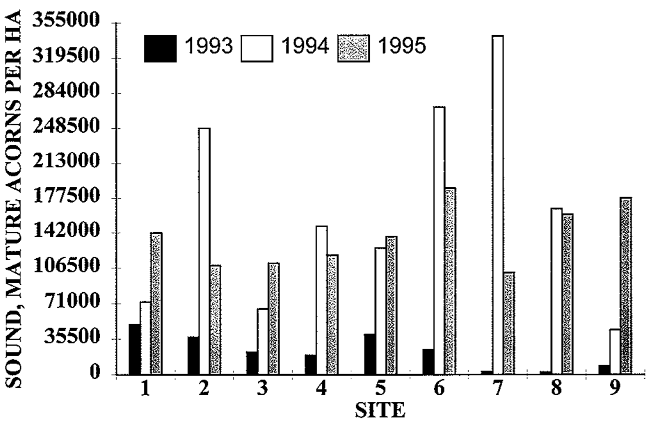

Figure 7.—*Sound, mature acorn production (acorns per hectare) by year and MOFEP site.*

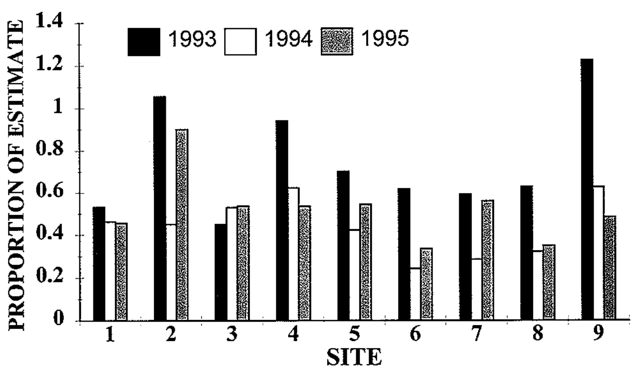

Figure 8.—*The proportion of the sound, mature acorn production estimate that the half-width of the 95 percent confidence interval made up for each year and MOFEP site.*

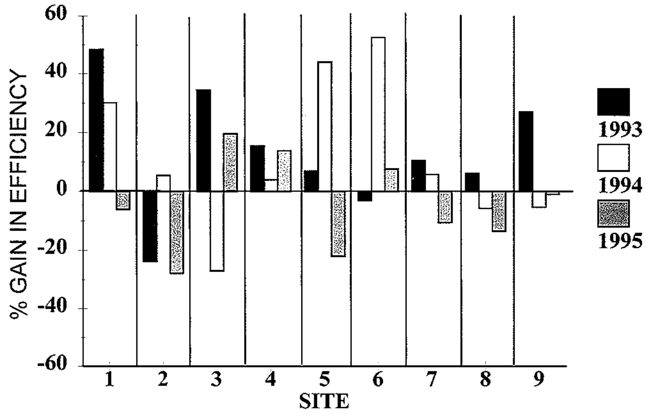

Figure 9.—*The percent gain in efficiency (reduction in variance) that results from stratification by ELT grouping when compared with the variance that would have resulted from a simple random sample by year and MOFEP site.*

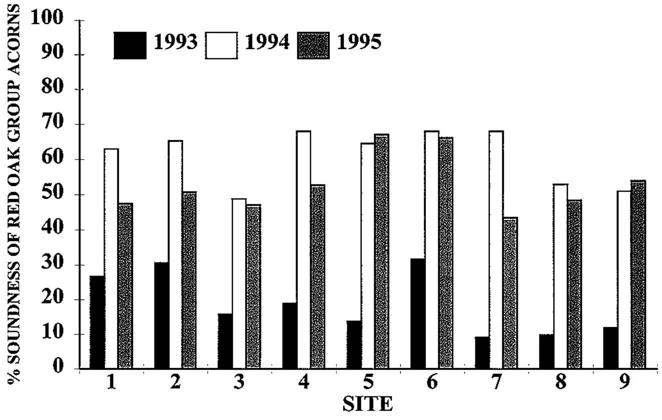

Figure 11.—*Percent soundness of red oak group acorns by year and MOFEP site.*

(fig. 10). In 1994, virtually all sound, mature production came from red oak group trees (>0.96 on all sites) (fig. 10).

Soundness of red oak group acorns ranged from 9 percent on site 7 in 1993 to 68 percent on site 6 in 1994 (fig. 11), and soundness of white oak group acorns ranged from 6 percent on site 7 in 1993 to 83 percent on site 9 in 1995 (fig. 12).

DISCUSSION

Production of sound, mature acorns varied considerably among treatments (sites), years, blocks, and ELT's. Such variation has been reported in a number of other studies (Christisen 1955, Dickson 1990, Goodrum *et al.* 1971, Schroeder and Vangilder 1997). In the current study, because the treatments had not been applied, the significant YEAR X TREATMENT interaction was no doubt the result of random variation in acorn production among the sites. The significant interaction illustrates the importance of collecting pre-treatment data. Although ideally, pre-treatment data should have been collected over a longer time period, the 3 years of pre-treatment data that were collected will help in the interpretation of post-treatment data.

Stratification by ELT group was a very important aspect of this study. With a simple random

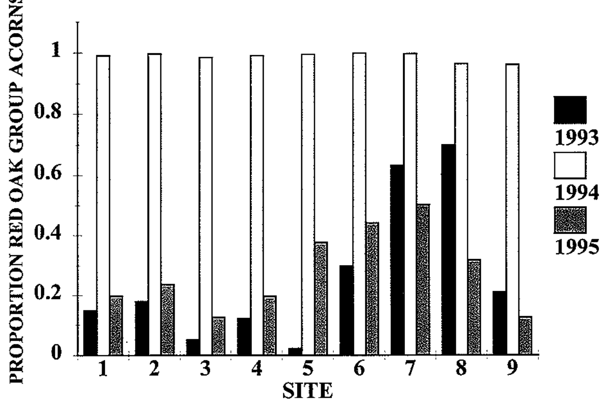

Figure 10.—*The proportion that red oak group acorns made up of the total sound, mature acorn production by year and MOFEP site.*

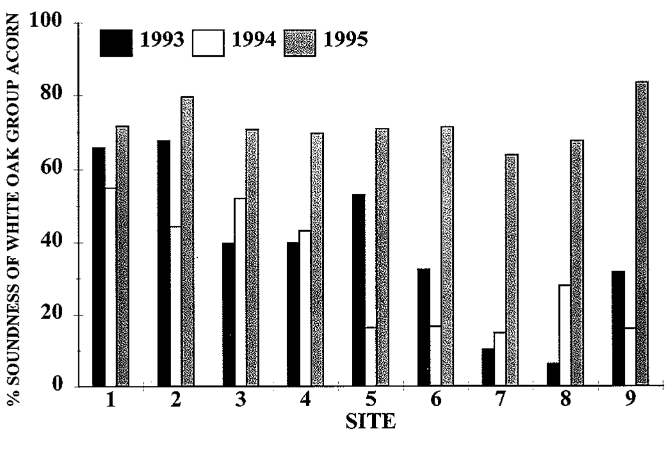

Figure 12.—*Percent soundness of white oak group acorns by year and MOFEP site.*

sample, important ELT effects could not have been detected. The production of sound, mature acorns, d.b.h. of oak trees, and mean canopy area of oak trees differed significantly among ELT's. In particular, sound, mature acorn production, d.b.h. of oak trees, and mean canopy area of oak trees were lower on plots in the "other" ELT group (primarily upland waterways) than on plots in the other three ELT groups. In addition, the analysis of variance of PCAN indicated that this difference in sound, mature acorn production among ELT's was due not only to the difference in the canopy area of oak trees among ELT's, but also to some inherent difference in productivity among ELT's. In other words, an "other" plot would produce fewer acorns than a ridgetop plot even when both plots had exactly the same amount of total canopy area of oaks.

Other measures of the canopy area of oaks have also been shown to be correlated with average acorn production in other studies (Goodrum *et al.* 1971, Schroeder and Vangilder 1997). Christisen (1955) reported that large-crowned oaks tended to produce more acorns than smaller crowned oaks.

Estimates of sound, mature acorns per hectare varied considerably among years and sites in this study. Other studies have also reported high levels of variability. Schroeder and Vangilder (1997) reported that average acorn production (N=5 years) ranged from 956 to 86,518 sound, mature acorns per hectare on 43 plots in the Missouri Ozarks. The maximum number of sound, mature acorns per hectare ranged from 27,000 to 106,000 on four study areas in Missouri from 1973 to 1976, while the minimum number of sound, mature acorns per hectare ranged from 2,500 to 6,000 (Christisen and Kearby 1984). Dickson (1990) reported that production of sound, mature acorns from 1959 to 1977 ranged from 5.4 to 637.5 kg/ha on an upland white oak-black oak-northern red oak site in the Sylamore Experimental Forest in the Ozarks of Arkansas. In a stream bottom white oak-black oak-northern red oak site on Sylamore, production ranged from 0.0 to 122.8 kg/ha. These relatively unproductive stream bottoms are similar to the "other" ELT group (upland waterways) in this study. One hypothesis that might account for lower average acorn production in "upland waterways" is that freezing temperatures in the spring occur there more often than higher up on slopes or ridgetops. If these freezing temperatures occur during flowering, many of the oak flowers will be destroyed and fewer acorns will be produced. In the spring, a hard frost may occur in these "upland waterways" (also called hollow bottoms) while the temperature will be well above freezing on the ridgetop (personal observation).

Variation about acorn production estimates was also quite high in some years on some sites. In 1993, on site 9 variation about the acorn production estimate was extremely high. An estimate of the number of plots needed to produce 95 percent confidence limits within 10 percent of the mean estimate (given the estimate and variance observed in 1993 on site 9) was 153 (Snedecor and Cochran 1967: 58). Although the required sample size might be slightly lower if stratification were taken into account, this rough calculation shows that, especially in years of low acorn abundance, the number of plots needed to get 95 percent confidence limits within 10 percent of the estimate is impractically large.

Almost all production of sound, mature acorns came from red oak group trees in 1994. In the other years, white oak group acorns made up a much higher proportion of the production. Dickson (1990) found that in 4 of the 19 years of his study almost no white oak acorns were produced. In another year, no red oak acorns were produced while production of white oak acorns was high. Dickson (1990) speculated that the asynchrony of acorn production between white oak and red oak group trees might be related to freezing temperatures in the spring, which might limit white oak acorn production in the subsequent fall but not limit red oak acorn production until the next fall (red oak group acorns take 2 years to develop). Sork *et al.* (1993) found that acorn crop size was correlated with spring temperatures during the season of maturation.

Soundness of acorns was also highly variable among species groups and among years in this study. Other studies have reported similar results. During the 4-year study reported by Christisen and Kearby (1984), soundness of acorns averaged 27 percent and ranged from 8 to 46 percent across the four areas studied. They also found that species differences were not consistent from area to area or from year to year. Soundness of white oak group acorns ranged from 13 to 42 percent across areas, while black oak group acorns (black and scarlet oak only) ranged from 11 to 50 percent. In an earlier study, Christisen (1955) reported that more than 50 percent of the acorns in two study areas in the Ozarks were damaged by insects.

Although not many firm conclusions can be drawn from 3 years of acorn production data, the results are similar to those observed in other studies. Because of the long-term nature of the MOFEP experiment, the potential for detecting patterns (if patterns exist) in sound, mature acorn production through time is great. In addition, the effects of forest management on sound, mature acorn production will be measured quantitatively for the first time.

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