PRODUCTION AND UTILIZATION OF ACORNS IN CLINTON COUNTY, MICHIGAN

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This is to certify that the

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By

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I. INTRODUCTION

Members of the genus Quercus have great commercial importance and considerable silvicultural study has been accorded them. A concomitant value, but one generally less recognized, is oak mast production as food for wildlife. Although often of vital importance to foresters and wildlife biologists alike, little is known concerning either acorn production or utilization. Basic, quantitative data are urgently needed, since these will materially aid the development of intensive oak forest management, whether for timber or game.

This study is an outgrowth of a long-term acorn investigation recently initiated at Michigan State College. The author attempted to determine some of the lesser known, but none-the-less important factors, influencing acorn production and utilization. These include: (1) amounts and variations in acorn production of individual trees, and species and site differences. The data were obtained largely by acorn counts of tree crowns; (2) quantitative measurements of the acorn crops as determined from seed trapping activities, and, (3) animal utilization of acorn mast, particularly rodent competition, obtained from population studies and acorn feeding experiments.

The study was conducted on two areas, approximately 40 miles apart, at Rose Lake and Maple Rapids, in Clinton County, Michigan. Both areas have upland oak-hickory forest types, although each differs strikingly in stand composition, land-use, and soils.

The field work began during late summer and continued through the fall months of 1952. Following the selection of sample trees, acorn counts of tree crowns were initiated and occupied most of September. Acorn trapping activities ran concurrently but extended into mid-October. The studies on animal populations and acorn utilization were conducted during the months of October and November.

II. REVIEW OF LITERATURE

Surprisingly few data are available concerning acorn production. Much of the literature extant is based upon short-term studies or observations. Interest in forest tree seed production received initial impetus in Germany in the years between 1870 and 1900 (Baker, 1950). Oak mast studies are of particular interest to foresters because oak stand regeneration is often inadequate. Korstian (1927) investigated some of the factors affecting germination and early survival of oaks in the southern Appalachian region and attempted to obtain quantitative data on production and biotic agencies responsible for destruction of the crop. Similar studies were conducted by Wood (1934, 1938) for chestnut oak in New Jersey. The most comprehensive and authoritative acorn study resulted from a 7-year investigation of five oak species in the southern Appalachians by Downs and McQuilkin (1944).

Additional studies, although of limited scope, were conducted by Cypert and Webster (1948), and Cypert (1951). Baker (1950) summarized the various investigations concerning seed production and presents an excellent discussion on the topic.

Quantitative measurements of acorn crops have been attempted. The most common method is based upon crown sampling by open, ground quadrats, variously delineated, and yielding a proportion of the total crop (Korstian, 1927; Wood, 1934; Allen and McGinley, 1947; and Cypert and Webster, 1948). The data obtained are subject to serious error, however, due to animal utilization. More reliable data accrues from sampling by specially constructed "seed traps" (Wood, 1938; Downs and McQuilkin, 1944; Easley and Chaiken, 1951; and Cypert, 1951), since they tend to exclude most animals.

The utilization of acorns by wildlife, although often of great importance, has not received the study commensurate with its scope and value. When available, acorns constitute a staple food for many game animals. Van Dersal (1938, 1940), and Martin, et al. (1951) summarized the many separate studies and records of acorn utilization by wildlife. Animal consumption of acorns often has a deleterious affect upon oak regeneration, depending upon the magnitude of the acorn crop and the animal population present (Korstian, 1927; Wood, 1934, 1938; Downs and McQuilkin, 1944: Cypert and Webster, 1947; Baker, 1950). Additional studies on population densities and acorn utilization of small mammals have been reported by Hamilton (1941), Allen (1943), Baumgras (1944), and Burt (1940, 1948). An excellent report on small mammal ecology at Rose Lake, Michigan, is that of Linduska (1950).

III. DESCRIPTION OF STUDY AREAS

Clinton county lies in the south-central part of the Lower Peninsula of Michigan. The land surface and soils differ greatly within the county, ranging from well-drained uplands to swampy depressions. The Rose Lake area is located in the southeast corner of the county. This vicinity is characterized by undulating to hilly topography. The soils are varied, but consist mostly of well-drained sandy loams and loamy sands, developed from calcareous glacial parent materials deposited as terminal moraines and till plains. Natural fertility and water retention is usually low (Johnsgard, et al. 1942). The woodlands generally consist of mixed hardwoods, although upland oak and oak-hickory forest types predominate.

The topography in the vicinity of Maple Rapids is slightly undulating to gently rolling. Most of the soils present have developed from calcareous glacial drift. A high clay content insures water retention during the growing season. Most of the woodlots in this region are composed of upland oak-hickory forest types.

The climate is temperate, with winters moderately cold and summers mild. The average annual rainfall of about 30 inches is fairly uniformly distributed throughout the year.

One of the study areas was located on the property of the Rose Lake Wildlife Experiment Station, and lies in Section 23, T5N, R1W (Bath Township). This area, designated as Rose Lake woodlot 6, is a 12-acre woods. Only the eastern half was suitable for study; the western portion consists mostly of immature timber. White oak (*Quercus alba*)[1] is the dominant tree species in the woodlot, with black oak (*Quercus velutina*) and pignut hickory (*Carya ovalis*) codominant and of secondary importance. Most of the white oaks are large, ranging 70 to 85 feet high and 20 to 25 inches in diameter. Ages vary from 150 to 200 or more years. The black oaks are generally smaller. The average diameter of 11 trees was 16.9 inches, and ranged from 14.2 to 21.2 inches. Height is very similar to that of white oak, averaging 74.7 feet. The trees age from 75 to 150 years old, but are thrifty and growing more rapidly than white oak. Crown vigor is good for both species, but the

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[1] Common and scientific names of woody plants are according to Gray's Manual of Botany, 8th Edition (Fernald, 1950).

crowns of black oak are smaller than the white oak. The stand has approximately normal stocking. A number of decadent white oaks are present and in some instances excessive crowns have developed, due to openings in the stand.

A dense understory has developed on the area following cessation of grazing in 1938 (Linduska, 1950). Black Cherry (*Prunus serotina*) and sassafras (*Sassafras albidum*) are in great abundance. Scattered clumps of blackberry (*Rubus sp.*), wild rose (*Rosa sp.*), and ground juniper (*Juniperus communis*) are also present, but are slowly being eliminated. A ground cover of June grass sod (*Poa pratensis*) is present on much of the area but considerable leaf litter has accumulated.

The topography is undulating to rolling, and the soil consists of Bellefontaine sandy loam - a medium to good black oak site (Gysel and Arend, 1953).

A second woodlot (number 1) was used for border tree studies, since well-developed borders were lacking in the former. This woodlot consists mostly of a pure stand of even-aged (about 100 years) black oak of moderate to good stocking on soil similar to that of woodlot 6. A partial selection cut in 1949 removed some of the timber.

White oak, pignut and shagbark hickory (*Carya ovata*) are codominant but of lesser importance. The woodlot has well-developed borders dominated by black and white oak. The fields surrounding the woodlot are in row crops or pasture.

The second study area is located in Section 10, T8N, R3W, one mile east of Maple Rapids, Michigan. It is approximately 40 miles north and west of the Rose Lake area. This 40-acre woodlot, locally known as the Lansing Woods, is a remnant stand of virgin timber. White oak dominates the stand in size and stocking. Many of the trees are 150 to 300 years or more in age. Diameters of sample trees ranged from 20.0 to 30.4 inches and averaged 22.7 inches. Many larger trees are present. Tree heights averaged 81.7 feet and varied from 78 to 91 feet high. These trees have thrifty, well-formed crowns and long, clear boles. Growth rate is fair, but generally best in the smaller trees. Red Oak (*Quercus rubra*) is codominant and an important component of the stand. It is slightly taller than the white oak (average 84.0 feet) but the diameter range of 10 trees was considerably smaller, 15.7 to 20.5 inches. The tree crowns are small, columnar, and thrifty. Growth rate is excellent - average diameter increment was slightly less than two inches during the past ten years. Red oak generally occupies the lower, but well-drained sites, which may be optimum for this species. Shagbark hickory, white ash (Fraxinus americana), swamp white oak (Quercus bicolor), black oak, and elm (Ulmus americana) are co-dominants and commonly interspersed throughout the stand.

All borders are dominated by huge white oaks, although red, black, and Jack oak (Quercus ellipsoidalis) also occur.

A dense, heterogeneous understory is present and is probably the result of the generally open canopy and site fertility. Hawthorn (Crataegus sp.), shadbush (Amelanchier sp.), and witherod (Viburnum cassinoides) are the most common shrubs.

A thick accumulation of leaf litter is present over most of the woodlot, but June grass has encroached onto the south border. The topography is undulating to rolling and the soil consists of Miami silt loam. This is a good to very good oak site (Gysel and Arend, 1953). Intensive farming for row crops and livestock characterizes the general vicinity of Maple Rapids.

Little if any timber has been removed in the past; however, cutting operations were initiated during the current year under an experimental management program.

IV. ANALYSIS OF SOME FACTORS INFLUENCING ACORN PRODUCTION

A number of factors are believed to influence forest tree seed production; however, their effects upon fruiting and seed development are poorly understood. Among the factors often considered are light conditions, site fertility, climate, and tree genetics. In this study, the effects of light upon acorn production were determined from crown counts of acorns, in relation to crown aspect. Site influence was evaluated from the variations in species production between the study areas, according to their site classes. Genetic factors were expressed as production variations of individual trees.

Materials and Methods

After a preliminary study, 10 trees of white oak and 11 black oaks were selected at Rose Lake woodlot 6. Ten trees each of white and red oak were chosen at Maple Rapids. This group constitutes a sample upon which long-term acorn studies will be based. The criteria for individual tree selection were adopted from Downs and McQuilkin (1944). Their study revealed acorn production differences were generally correlated with bole diameters.

The bulk of the acorns for white oak were produced by trees 20 to 32 inches d.b.h., with greatest production at about 26 inches. That for red oak was 16 to 25 inches and was best for 21 inch trees. Black oak production increased proportionately with diameter. Crown size and thrift were also related to production potential. The larger crowned trees generally produced the largest crops, particularly if growth was vigorous.

In the present study white oaks were restricted to trees 30 inches d.b.h. or under. Most of the red and black oaks ranged from 15 to 22 inches, and were the largest trees available. All trees selected possessed medium-sized, thrifty crowns, as opposed to excessively large or small forms. Crown symmetry was also considered since it affected trap placement. Measurements of sample trees are presented in Table 4.

In order to correlate acorn production with crown structure, five trees of each species, for both sites, were chosen for special study. The trees were ascended by means of a 100-foot half-inch manila rope and crowns were inspected by climbing the main branches. Selection of trees was related to ease of crown accessability; i.e., one large limb within 50 feet of the ground. Upon entering the crown all limbs were numbered and diameters (2 inch minimum) and lengths estimated and recorded. All limbs were designated as "exposed" or "lower" crown branches. Limb position relative to origin on the trunk was the criterion used; however, in some instances general limb condition as indicated by natural pruning was used, since this was a reflection of light quality and intensity.

In addition, the crown was divided into four 90 degree quadrants and each limb classified as north facing, south facing, etc., on the basis of point of origin and subsequent growth habit. Arbitrary designations often resulted, particularly with twin-headed crowns. Errors in judgment are considered compensatory.

Acorn counts were conducted for all limbs, starting at the top and descending. The foliage of each limb was carefully scrutinized and counts of well-developed acorns recorded. The observer was usually within a few feet of the acorn bearing outer branchlets, but this varied with accessibility and safety. Most acorns were visible and easily discernible. Slight air currents often revealed acorns hidden by foliage. An estimated 5 to 10 percent of the acorns were probably not counted, depending upon tree species and size of crown, thus the counts may sometimes be low.

In a year of high production a sampling method would have been desirable since individual counts are laborious and time consuming. Preliminary study showed close agreement between sample area counts and total limb counts.

The trees at Rose Lake woodlot 6 were censused between September 7 and 11, and those at Maple Rapids September 16 to 19. In addition, 8 black and 4 white oak border trees (woodlot 1) were climbed from September 12 to 15. Six Maple Rapids border trees (3 each of red and white oak) were censused during September 20 to 23. Several others were climbed for observation.

Results and Discussion

Crown Structure and Acorn Production

Interior trees

Analysis of Table 1 reveals striking differences in quantity of seed produced between the exposed and lower crown categories of sample trees. Although there is considerable variation among species, the trends are generally similar. Individual tree counts are in close agreement with aggregate production of the group. Total exposed crown production was 3.4 times greater than lower crown yield for Rose Lake white oak, 11.2 times greater for black oak, 5.5 times greater for Maple Rapids white oak, and 5.6 times greater for red oak.

Table 1

Distribution of Acorn Production, Number of Limbs, and Acorns Per Limb of Interior Trees, from Crown Counts*

Species and Locality	Item	Exposed Crown					Lower Crown				
		Limb Aspect				Totals and Average	Limb Aspect				Totals and Average
		North	South	East	West		North	South	East	West	
White Oak Rose Lake	Number of Acorns	0	41	76	51	168	13	4	29	4	50
	Number of Limbs	2	5	9	6	22	8	7	10	3	28
	Acorns Per Limb	0.0	8.2	8.4	8.5	7.6	1.6	0.6	2.9	1.3	1.8
Black Oak Rose Lake	Number of Acorns	193	784	33	294	1,304	27	35	49	5	116
	Number of Limbs	6	6	4	5	21	8	7	7	2	24
	Acorns Per Limb	32.1	130.6	8.2	58.8	62.1	3.4	5.0	7.0	2.5	4.8
White Oak Maple Rapids	Number of Acorns	154	607	244	635	1,640	56	51.	69	121	297
	Number of Limbs	6	9	8	13	36	8	7	7	10	32
	Acorns Per Limb	25.7	67.4	30.5	48.8	45.5	7.0	7.3	9.9	12.1	9.3
Red Oak Maple Rapids	Number of Acorns	9	50	14	34	107	4	4	7	4	19
	Number of Limbs	3	9	4	8	24	4	3	5	6	18
	Acorns Per Limb	3.0	5.5	3.5	4.3	4.5	1.0	1.3	1.4	0.7	1.1

*Based on totals and averages of five trees for each species

These differences represent the innately greater production of upper crown limbs. Number or size of limbs is not a factor. Table 2 shows slightly greater numbers of upper crown limbs for Maple Rapids trees, but Rose Lake trees have more lower branches. Although not expected, the diameters of upper and lower limbs are remarkably similar. No difference in size exists for Rose Lake trees; the lower limbs of Maple Rapids trees are only slightly larger than the upper limbs (.8 and 1.0 inch greater diameter for red and white oak, respectively). Lower limbs averaged slightly longer than their counterparts. The difference was greatest for red oak (9.6 feet).

Average production per limb also varies but is directly related to tree yield. The highest producing black oak had an average exposed limb yield of 229.8 acorns but only 9.8 acorns per lower limb. The average production for all black oaks was 62.1 and 4.8 acorns per exposed and lower limb. Average production per branch for all trees is closely similar to total upper-lower crown acorn ratios of a group. The data appear to confirm the contention that production of high-forest trees in closed stands is confined to tops of trees (Toumey and Korstian, 1947).

Table 2

Number, Range, and Mean Diameters and Lengths of Interior Tree Crown Limbs of Five Sample Trees for Each Species

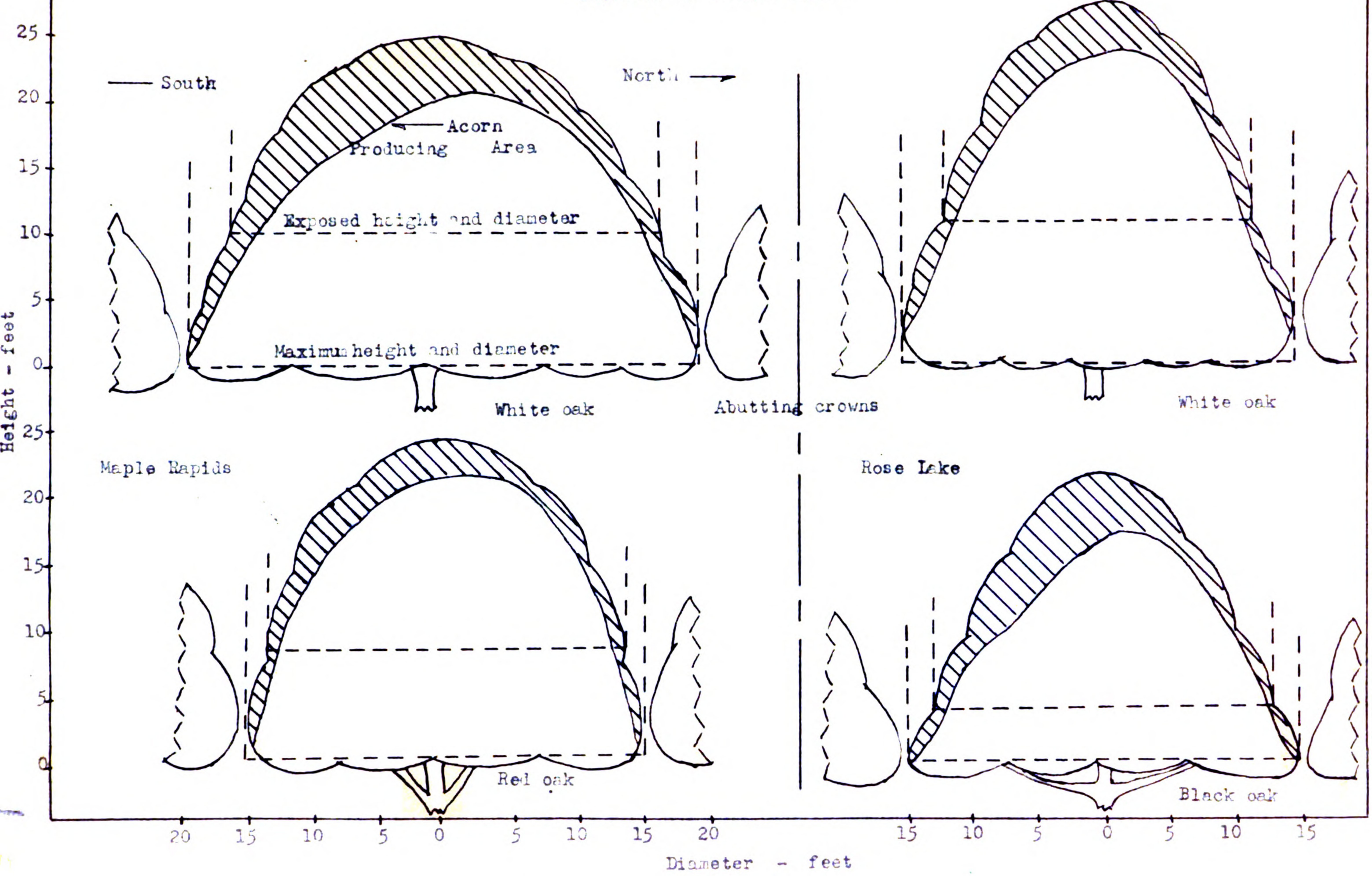
	Exposed Crown					Lower Crown				
	Total No. of	Diameter (inches)		Length (feet)		Total No. of	Diameter (inches)		Length (feet)	
Species	Limbs	Range	Mean	Range	Mean	Limbs	Range	Mean	Range	Mean
White Oak	22	3-8	4.9	6-35	17.5	28	2-8	5.0	10-32	19.1
Black Oak	21	3-8	3.9	6-30	11.4	24	2-6	4.0	6-35	15.2
White Oak	36	3-10	5.4	10-34	20.6	32	3-10	6.2	8-30	26.5
Red Oak	24	3-6	4.0	12-25	17.3	18	3-9	5.0	15-44	26.9

Limb aspect (azimuth) also modifies production as noted in Table 1. Average per limb production is a better index than total yield since the number of limbs is considered. South facing exposed crown limbs usually produced the greatest quantity of acorns. Average limb production for all black oaks was, south 130.6 and north 32.1 acorns - a 4 to 1 ratio. West limbs produced 58.8 acorns to 8.2 per east limb. Maple Rapids white oak averaged 67.4 acorns per south limb and 25.7 for north; the west face production was 48.8 to 30.5 acorns per east limb. The lower aspect ratios of white oak probably represent differences in crown development; i.e., larger, more open form.

Lower crown production does not appear to be correlated with limb azimuth, since no definite trend is discernible. This is expected because most of the light reaching this level is diffused and equally distributed.

Interpretation of acorn production as modified by crown position is best illustrated by Figure 1. The crown diagrams are based upon average measurements of individual study trees (Table 4). Crown measurements were obtained after leaf-fall was completed. The outlines

Figure I. Average Crown Conformation and Acorn Producing Area of Sample Trees in the Interior of Forest Stands



are drawn to scale and represent real differences in conformation among species and between sites. The relative acorn producing areas are based on data from Table 1, and graphically illustrate the effects of insolation upon seed production. Although the diagrams represent south-north aspects, a somewhat similar relationship exists for west-east faces.

The shading effects of contiguous trees (abutting crowns) delimits the height of exposed crown and is expressed in foliage changes; i.e., lower limbs have large, thin, verdent leaves. Severe pruning is often evident in the lower limbs. White oak lower limbs have higher shade tolerance and therefore a deeper lower crown. Foliage densities also modify production and result in lower north and east upper crown production through light energy interception by the reverse face. Depth of light penetration varies with foliage density and differs within species and sites.

According to Baker (1950), and Toumey and Korstian (1947), insolation directly affects seed production since a high rate of photosynthesis and rapid accumulation of carbohydrates is favored by high temperatures and plenty of light. A high food reserve (starch) seems necessary for adequate flowering and bud formation. Solar energy as heat may directly affect flower and bud survival. Wood (1938) believes there is a physiological limit to the number of acorns that can be supported by a tree. The low production of the lower crown is probably due to the inability of the shaded foliage to produce reserve food in excess of the amounts needed for subsistence and growth.

Border trees

Adequate data for border tree analyses are limited to the black oak of woodlot 1 at Rose Lake (Table 3). Exposed and lower crown categories were not feasible for border oaks since all portions of the crown are considered exposed. However, the data showed a decidedly greater production of acorns born on the upper limbs of the trees. For example, one south border black oak had 7 upper crown limbs which averaged 81.3 acorns per limb (total 569), while 13 lower limbs produced only 32.2 acorns per limb, with a total yield of 475. Similar trends were noted for all border trees regardless of aspect. Figure 2 illustrates the relation of crown surface and acorn production for north and south border black oaks.

Aspect differences in border production of black oak are correlated with number of limbs and are a function

Table 3

Distribution of Acorn Production, Number of Limbs, and Acorns Per Limb of Border Trees, from Crown Counts

Species and Locality	Item	North Border					South Border					West Border				
		Limb Aspect				Totals and Ave.	Limb Aspect				Totals and Ave.	Limb Aspect				Totals and Ave.
		North	South	East	West		Nor.	Sou.	East	West		Nor.	Sou.	East	West	
Black Oak* Rose Lake	No. of Acorns	61	6	19	20	106	198	672	227	401	1,500	39	26	4	258	327
	No. of Limbs	16	2	6	4	28	7	16	10	10	43	4	3	3	14	24
	Acorns Per Limb	3.8	3.0	3.1	5.0	3.8	28.3	42.0	22.7	40.2	34.0	9.8	8.7	1.3	18.4	24.6
White Oak** Rose Lake	No. of Acorns	92	4	5	127	228	-	-	-	-	-	6	26	0	90	112
	No. of Limbs	16	1	1	6	24	-	-	-	-	-	3	6	0	11	20
	Acorns Per Limb	5.7	4.0	5.0	21.1	9.5	-	-	-	-	-	3.0	4.3	0	8.2	6.2
White Oak+ Maple Rapids	No. of Acorns	-	-	-	-	-	160	666	500	400	1,726	66	142	145	931	1,284
	No. of Limbs	-	-	-	-	-	3	10	9	7	29	9	8	8	15	40
	Acorns Per Limb	-	-	-	-	-	53.3	66.5	55.6	57.2	59.6	7.3	17.9	18.1	62.0	32.1

*Three trees for North and South Border, two on West Border
**Two trees each Border
+One tree South Border, two West Border

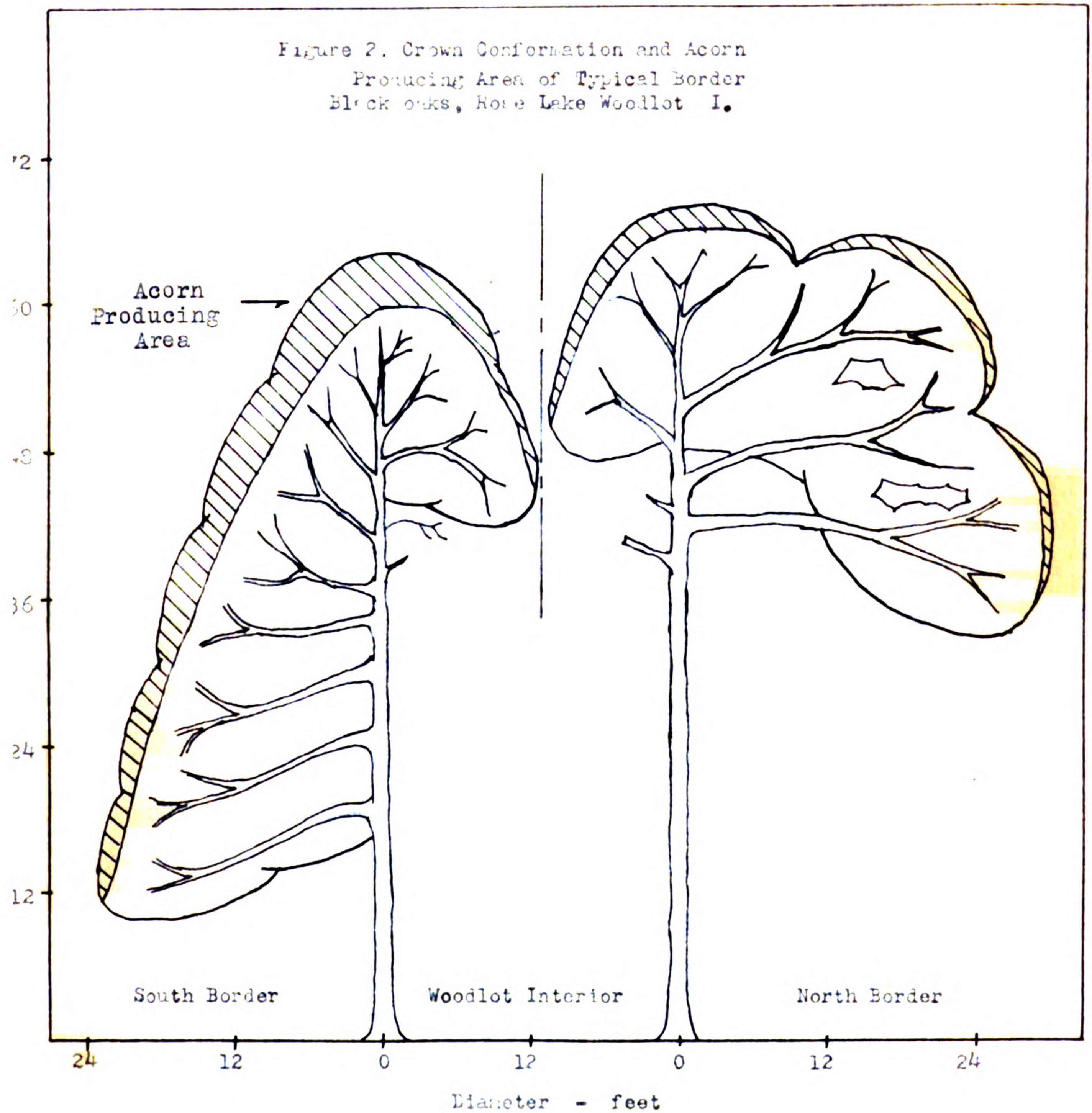


Figure 2. Crown Conformation and Acorn
Producing Area of Typical Border
Black oaks, Rose Lake Woodlot I.
Acorn
Producing
Area
South Border
Woodlot Interior
North Border
12
24
36
48
60
72
24
12
0
12
0
12
24
Diameter - feet

of border exposure. The south face of a south border tree always had relatively more limbs than any other face, consequently total production was greater. Average production per limb, however, was only slightly higher for south limbs (42.0 acorns) than west (40.2), but about twice as high as north (28.3) or east (22.7). The side opposite the border exposure was always lowest in either category. The production of north border black oak was considerably lower than south or west border trees, therefore the production trends according to aspect could not be accurately interpreted.

White oak border trees (woodlot 1) were few and produced poorly. North border trees have shade tolerant lower limbs that usually extend outward, forming extensive canopies. An excellent example of insolation effect was noted for one white oak. A lower limb, estimated at one-eighth the total crown area, projected beyond the northwest corner of the woodlot and accounted for 112 of the 171 acorns (65.5 per cent) tallied for the tree.

Maple Rapids border white oaks were extremely large, but did not have high production commensurate with size. Only 2 of 8 trees climbed were producing well, the others largely failed. Disposition of acorns were similar to that of black oak at Rose Lake.

Crown formation and growth habit differences of border black oaks are presented in Figure 2 and are based upon average tree measurements. Although these trees are similar in age, bole diameter, and height, growth form varies greatly and seem to reflect responses to light. The north border trees are severely pruned; the limbs are few and widespreading. Acorn production appears to be sacrified in favor of tree growth. The extremely poor conditions of these trees suggest that other factors may be influencing growth form. South border trees contain many large lower limbs which develop numerous branchlets and dense foliage. West and east border trees are intermediate in stature: west trees are similar to south border form, and east trees closely allied to north.

Acorn Production Variations and Comparative Yield of Study Trees

Fruiting cycles

Annual variations in seed production are commonly observed in oaks. The fluctuations are often striking in occurrence and a cyclic phenomenon has been ascribed to them. A uniform cycle does not appear to exist, however. Baker (1950) reports a 5 to 6 year peak production for European oak between 1874 and 1893, but alternate year highs are indicated. Wood (1934) observed high production for chestnut oak during 1928, followed by two years of low yield. For oaks in general, Van Dersal (1938) believes full crops are borne at intervals of 8 to 10 years, but some seed is produced almost annually. Downs and McQuilkin (1944) reported a peak production for 1938 and 1942 during their seven year study, but concluded that a longer period is needed to determine the periodicity of the cycle (3 to 4 years) if it exists. Allen (1943) believes an alternate year production is evident among individual trees, thus some seed is produced almost every year. A limited amount of acorn crop data has been obtained by the Rose Lake Station since 1939. The sampling method is that of Allen and McGinley (1947) but has been variously modified since its inception. Only a few (mostly isolated) trees constitute the sample. The success of the acorn crops are given below. A peak crop is indicated once in 3 to 4 years but it is not consistent.

Year	Crop	Year	Crop
1939	Excellent, all oaks	1946	Very poor, all oaks
1940	Very poor, all oaks	1947	Poor, all oaks
1941	Good, red oak exceptional	1948	Fair, black oak
1942	Fair, white oak failed	1949	Good, all oaks
1943	Poor, red oak fair	1950	Fair, red and white oak
1944	Poor, all oaks	1951	Poor, red oak exceptional
1945	No data	1952	Poor, red and white oak failed

Note that 1952 was considered a poor year, particularly for white and red oak. Some seed was produced by Maple Rapids white oak, and black oak. Acorn crop failures are the rule rather than the exception, thus data obtained during a poor year are significant.

The cycles have been explained on the basis of the carbon-nitrogen ratio theory. A favorable (carbon) ratio results in reserve food accumulation, and this is expressed in high flower production. After a tree produces a heavy crop of seed it usually requires a period of several years for the accumulation of sufficient food reserve to make another heavy seed year possible (Toumey and Korstian, 1947). Baker (1950) largely repudiates this concept because greatly increased seed production has been noted following application of nitrogenous fertilizer (Chandler, 1938, Detweiler, 1943).

Climatic conditions such as spring frosts, exceptionally dry or wet summers, etc., may directly affect seed production through pollination failure and flower bud mortality. Inadequate fertilization was not found to be significant in chestnut oak flowering, according to Wood (1938). He observed a progressing mortality (99.5 percent) from time of fertilization to acorn maturity. Baker (1950) believes that the destruction of a potentially heavy crop prevents the expenditure of stored nutrients, or otherwise upsets the normal cycle, and commonly calls forth a heavy crop the following year. During crown counts the author observed several low producing black oak trees whose branches contained numerous small, dead acorns (often 5 or more per cluster), indicating a high summer mortality. High acorn flower counts were noted for these trees, thereby substantiating Baker's observation.

Individual variation

Seed production is greatly affected by crown class (dominance) and reflects the direct stimulus of light upon size and thriftiness of tree crowns (Toumey and Korstian, 1947; Baker, 1950; Cypert, 1951). Downs and McQuilkin (1944) state that "within a species, intensity of acorn production per unit of crown volume is approximately the same for all trees, and that total acorn production therefore is related directly to size of crown, and indirectly to d.b.h." However, they did not find high acorn production to be consistently correlated with such tree characteristics as d.b.h., crown diameter, age, or growth rate.

Attempts to relate acorn production to tree development in the areas studied generally indicate positive correlation, although wide discrepancies occur (Table 4). The highest producing black oak has the largest crown diameter and is above average in all categories except growth rate. The second highest producer, however, is below average in all categories but has the best growth rate. The highest producing Maple Rapids white oaks also possessed the largest crowns, and were above average in all other classes. Several large crowned trees produced low acorn crops, however. Downs and McQuilkin (1944) found that well-formed, thrifty crowns were the best producers. A favorable crown position in the canopy is expressed in increased bole increment and therefore a larger d.b.h. This is true for Maple Rapids white oak, but not for black oak. Apparently, no single, valid criterion exists for judging the potential production for all trees.

The possibility exists, that genetic factors also control seed production. It has been observed that some trees consistently bear good crops of seed, even in poor years, while others are "vegetative" and usually fail

Table 4

Tree Measurements and Acorn Production of Interior Study Trees

Species and Locality	Tree No.	Radial Growth 10 Years mm.	Age Years	D.B.H. Inches	Height Feet	Crown Height Total Feet	Crown Height Exposed Feet	Crown Diameter Maximum Feet	Crown Diameter Exposed Feet	Total Acorns Per Tree Number
White Oak Rose Lake	1	-	-	23.0	68	28	20	37.5	26.6	64
	2	14	193	22.2	70	22	20	32.6	22.1	8
	3	-	-	25.5	72	27	17	30.0	21.3	57*
	4	-	-	20.8	86	30	15	28.5	25.0	13
	5	8	198	20.6	84	25	25	26.0	24.1	19*
	6	10	185	20.3	76	26	16	38.3	27.3	19*
	7	-	-	20.2	77	23	10	24.5	10.5	97
	8	15	192	23.8	81	38	13	34.7	28.1	38*
	9	-	-	23.0	77	27	17	34.0	30.0	57*
	10	13	120	14.7	76	21	10	17.2	17.2	36
	Mean	12	178	21.4	76.7	26.7	16.5	30.5	23.4	40.8
Black Oak Rose Lake	1	16	75	15.6	81	26	16	33.2	21.9	39
	2	-	-	17.5	77	32	20	28.8	28.8	400*
	3	-	-	16.0	66	24	24	30.5	23.3	500*
	4	-	-	20.7	86	26	26	30.5	27.5	75*
	5	13	96	16.8	87	24	24	36.1	35.0	150*
	6	-	-	17.2	70	17	17	29.5	23.7	25
	7	14	124	21.2	79	16	10	40.0	28.9	1,525*
	8	19	82	18.2	86	28	18	32.3	26.8	30
	9	-	-	14.2	57	19	19	26.5	26.5	138
	10	20	85	14.2	63	14	14	25.9	24.6	1,188
	11	-	-	14.8	70	15	10	17.0	17.0	-
	Mean	16.4	92	16.9	74.7	21.9	18.0	30.0	25.7	408.0
White Oak Maple Rapids	1	8	-	25.5	80	22	22	38.5	34.2	178**
	2	12	-	30.4	87	28	18	42.1	40.7	1,989
	3	7	-	22.6	83	20	10	34.4	32.3	133**
	4	11	-	20.1	79	20	14	28.0	25.1	88**
	5	15	202	21.3	78	27	20	33.6	32.2	28
	6	9	168	20.4	88	22	12	41.8	41.8	88**
	7	9	-	25.3	91	30	12	44.5	32.9	670
	8	11	248	20.0	78	28	8	37.9	18.8	117
	9	12	-	19.8	78	24	12	32.8	23.4	23
	10	-	-	21.9	75	20	10	40.0	34.4	177**
	Mean	10.4	209	22.7	81.7	24.1	13.8	37.8	31.8	349.0

*Estimates computed from trap collections
**Revised acorn counts due to previous fall

Table 4 (Continued)

Species and Locality	Tree No.	Radial Growth 10 Years	Age	D.B.H.	Height	Crown Height Total	Crown Height Exposed	Crown Diameter Maximum	Crown Diameter Exposed	Total Acorns Per Tree
		mm.	Years	Inches	Feet	Feet	Feet	Feet	Feet	Number
Red Oak	1	20	88	19.9	82	23	23	32.4	32.4	-
Maple	2	11	-	16.7	85	27	15	28.4	25.4	10
Rapids	3	17	-	16.0	76	22	15	28.9	24.2	12
	4	14	83	17.5	82	22	15	29.0	26.2	-
	5	34	-	20.5	80	18	13	33.9	24.9	44
	6	26	76	17.1	88	27	17	33.4	24.5	27
	7	-	-	18.7	83	19	10	28.8	28.8	33
	8	29	-	17.8	74	33	15	33.5	27.9	-
	9	39	51	15.7	82	37	20	27.5	27.5	-
	10	12	66	16.5	88	15	20	24.3	22.9	-
	Mean	22.4	73	17.6	84.0	24.3	15.8	30.0	26.5	25.2

to produce (Wood, 1934, 1938; Toumey and Korstian, 1947; Cypert and Webster, 1947; Baker, 1950, and Cypert, 1951).

Border tree production is generally correlated with light intensity. Greater insolation for south border black oaks results in a larger crown volume than that of north border trees (Figure 2). Crown thrift is expressed in increased growth rate in the south-facing trees. The west border black oaks are generally smaller trees but are vigorous and have thrifty crowns; they are intermediate in production. White oak production at Maple Rapids is not related to crown volume but may be due to insolation, per se, since all trees are overmature and therefore lack vigor. High acorn production was counted on two of the three south and west border trees censused. Similar east and north border trees had consistently low production.

Species and area differences

The trap data presented in Table 7 reveals an obvious production differential between species. Total trap collections were 7.4 times greater for Rose Lake interior black oak compared to white oak. Estimated acorn production (Table 4), based on crown counts and trap collections (see page 56), was 10 times greater for black oak (408.0 acorns per tree) than it was for white oak (40.8 acorns). Similarly, Maple Rapids white oak trap counts exceeded those of Rose Lake white oak by 8.6 times. Estimated average production was 349.0 acorns per tree for the former and 40.8 for the latter, also an 8.6 to 1 ratio. The red oak crop was almost a complete failure, in this respect it closely approximated that of Rose Lake white oak.

Adequate explanation of the production differences noted is not feasible because the factors responsible are poorly understood. Several facts are evident, however. Within an area, acorn production varies considerably between species for any one year. Although it cannot be predicted, the production trend of Rose Lake may be reversed in 1953. This tendency is highly improbable for Maple Rapids since another fail year is predicted for red oak on the basis of flower counts. Judging from acorn and cup remains red oak produced an exceptionally good crop in 1951. Although 1952 was a poor production year, some few trees bore moderate crops; this is considered normal (Baker, 1950).

White oak production differences between areas may be due to soil, or to climatic conditions; i.e., frosts, etc. The effects of local soil and other site influences upon seed production has not been determined. Site quality may have a direct influence in that it helps determine the amounts of food materials stored in a tree. Seed production requires large amounts of potash and nitrogen. Soils deficient in these elements produce trees which yield small, inferior crops of seed (Toumey and Korstian, 1947). Site may also influence stand density and crown differentiation (Baker, 1950). The Rose Lake site is considered medium for oak. Site quality is greatly superior at Maple Rapids and is probably optimum for both red and white oak.

Comparative production of interior, border, and isolated trees

It is commonly stated that border or isolated trees usually produce earlier, larger, and more consistent crops of acorns than do forest-grown trees (Wood, 1934, 1938; Toumey and Korstian, 1947; Cypert and Webster, 1948; Baker, 1950). Allen and McGinley (1947) believe that interior woodlot trees are unimportant as acorn producers; the bulk of the acorn crop of value to wildlife, according to them, is produced by isolated and border trees.

The author believes such statements are unjustified and unsupported by data. Table 5 presents a summary of

Table 5

Comparative Acorn Production of Interior, Border, and Isolated Trees, Based on Crown and Trap Counts, and Ground Estimation*

Item	Black Oak, Rose Lake**				White Oak, Maple Rapids				All Species and Areas Combined			
	Total Sample Trees	Number of Trees Producing Crops			Total Sample Trees	Producing Crops			Total Sample Trees	Number of Trees Producing Crops		
		Low+	Medium	High		Low+	Medium	High		Low+	Medium	High
Interior												
Trees	47	39	5	3	18	12	4	2	90	76	9	5
Percent of Total	-	83.0	10.6	6.4	-	66.7	22.2	11.1	-	84.4	10.0	5.6
Border												
Trees	105	90	8	7	13	9	2	2	166	138	14	14
Percent of Total	-	85.6	7.7	6.7	-	69.2	15.4	15.4	-	83.2	8.4	8.4
Isolated												
Trees	6	4	2	0	5	3	1	1	53	43	7	3
Percent of Total	-	66.6	33.3	0	-	60.0	20.0	20.0	-	81.1	13.2	5.7

*See page 56 for ground estimation method
**Includes nearby Okemos Woods
+ Low production equals 0 to 100 acorns, medium - 101 to 500, and high over 500.

observed acorn production for the growth form categories in question, based upon tree counts, trap collections, and ground observations (see page 56 for latter method).

The crop failure of Rose Lake white oak, and for red oak, was not confined to interior trees but extended to border and single trees as well. Only one of 45 white oak samples in the vicinity of Rose Lake had a high acorn crop. Similarly, of 21 red oaks only one was productive. The proportion of high producing black oak trees in interiors and borders is approximately equal (6.4 to 6.7 percent). All isolated trees sampled (6) failed to produce seed in quantity, although all were large crowned trees. Furthermore, acorn production of interior trees was greater, in both individual production and average per tree, than it was for border trees. It is of interest to note that of the 7 high producing border trees listed, 5 were located on a north border (Okemos Woods), 3 of these were contiguous along 40 feet of border, indicating possible inherent genetic characteristics.

The production trend for Maple Rapids white oak is comparable to that of black oak, although fewer trees were sampled. The production differential between high producing interior and border trees is minor (11.1 and 15.4 percent, respectively). It is noted that approximately one out of 3 trees had medium or better production; for black oak this ratio was one to 6 or 7 trees. The significance, if any, is not known.

The summary for all species and areas combined is in general agreement with the above analyses. It is concluded therefore, that superior location of border or single-trees, with regard to insolation and root competition, does not necessarily result in increased production, per se. The crowns of these trees are usually larger than interior trees, but the assumption that acorns are evenly distributed over the entire crown has been disproved. Tree vigor, including crown thrift, can also be high for interior trees, with suitable sites and stocking. This is apparently true for black oak, and possibly for Maple Rapids white oak, even though the latter is a virgin stand. In addition, the total acorn production of a woodlot interior is considerably greater than it is for borders. According to Gysel and Arend (1953), the average woodlot on medium to good site contains 60 to 80 trees, 12 inches d.b.h. or over, per acre. On this basis, there are between 720 and 960 trees (mostly black oak) in the interior portion of woodlot 1 (12 acres). Only 41 border oaks were recorded from the perimeter of this woods. Even if average production per interior tree were lower than that for border trees, the total interior production would still be overwhelmingly greater. Furthermore, single-trees are often few and isolated. The value of these trees in providing acorn food for animals of low cruising radius is negligible, although Allen (1943) noted some squirrel utilization of these acorns during late winter.

The large acorn crops often noted for single-trees (includes fencerows) may not represent natural conditions. Allen (1943) records a large white oak that annually produced at least one bushel of acorns (approximately 10,500) between 1937 and 1939. The author also observed comparable production for a white oak growing within a wheat field, but concluded that application of nitrogenous fertilizer probably induced the copious acorn crop.

V. THE USE OF TRAPPING DATA FOR ACORN PRODUCTION ESTIMATIONS

Sampling methods are commonly used for estimating acorn crops. Sample collections are useful in providing a basis for calculating total tree yield, composition of the crop, and utilization by wildlife. The most commonly employed method has been that of selecting a sample area on the ground beneath a tree crown and collecting or counting the fallen acorns. These ground quadrats are usually arbitrarily located, and variously delineated (Korstian, 1927; Wood, 1934; Allen and McGinley, 1947; Cypert and Webster, 1948). The total yield is calculated from the proportion of the known sample area to that of the total crown. Estimation of tree yield by this method would generally produce accurate results since a total segment of the crown is considered. However, animal activity is often great and undoubtedly affects the validity of the counts.

In order to obviate this factor, specially constructed "seed traps" have been devised for use in obtaining unbiased acorn samples, (Wood, 1938; Downs and McQuilkin, 1944; Cypert, 1951, and Easley and Chaiken, 1951). The traps are usually 1/4 mil-acre in area and covered with hardware cloth to exclude animals. Many of these traps are expensive to build, usually bulky, and often not completely animal (rodent) proof, this is particularly true of those constructed by Downs and McQuilkin. Estimates of acorn yield are usually determined from the relationship of trap collections and tree crown-trap volume ratios.

Materials and Methods

A modification of the seed trap reported by Easley and Chaiken (1951) was developed for a long term acorn production investigation and was used in this investigation. The trap body consists of triangular sections of treated canvas sewn together in pyramidal form. It is supported by a welded frame of quarter-inch steel rods, each 3.3 feet in length, producing a trap 1/4 mil-acre in area. A collection basket made of stapled fly-screening is attached to the funneled lower body by means of a wire pin. The trap mouth is covered with one or two inch mesh galvanized wire, the latter was used for red oak. The trap is elevated into position by means of four softwood stakes. The completed unit is shown in Figure 3.

Figure 3. Acorn trap in operation on south border of Rose Lake woodlot 1.

Two traps were placed under each tree. Consideration was given to crown symmetry and limb position. The traps usually sampled dissimilar portions of the crown; i.e., dense and sparse foliage. Undesirable trap position necessitated a slight relocation of several traps soon after collecting operations had begun.

In close proximity to each trap a stake was placed marking the center of a circular 1/4 mil-acre (22.3 inch radius) open-quadrat. The ground litter within the quadrat area was searched for fallen acorns and cups. These were recorded and ejected from the plot.

Traps at Rose Lake woodlot 6 were placed in operation between August 28 and September 2 and first checked on September 8. Trapping operations at Maple Rapids began during September 3 to 5. Traps were visited at weekly intervals (one day lag for Maple Rapids), checked, and emptied. Acorns collected were sorted according to the classes given in Table 6.

In addition, traps were also placed under six black oaks on the north and south border of Rose Lake woodlot 1. For each tree one trap and quadrat was located on the border side, the other was interior. Trapping began on September 11 and was first checked on September 22.

Results and Discussion

Period of Acorn Fall Based Upon Trap Collections

A generally uniform trend for all species is noted for weekly trap collections in Figure 4. The peak fall period occurred during the week of September 8 to 16. Forty percent of the Maple Rapids white oak acorns fell during this period. Forty-four percent more fell during the following 3 weeks, thereafter the fall ceased abruptly.

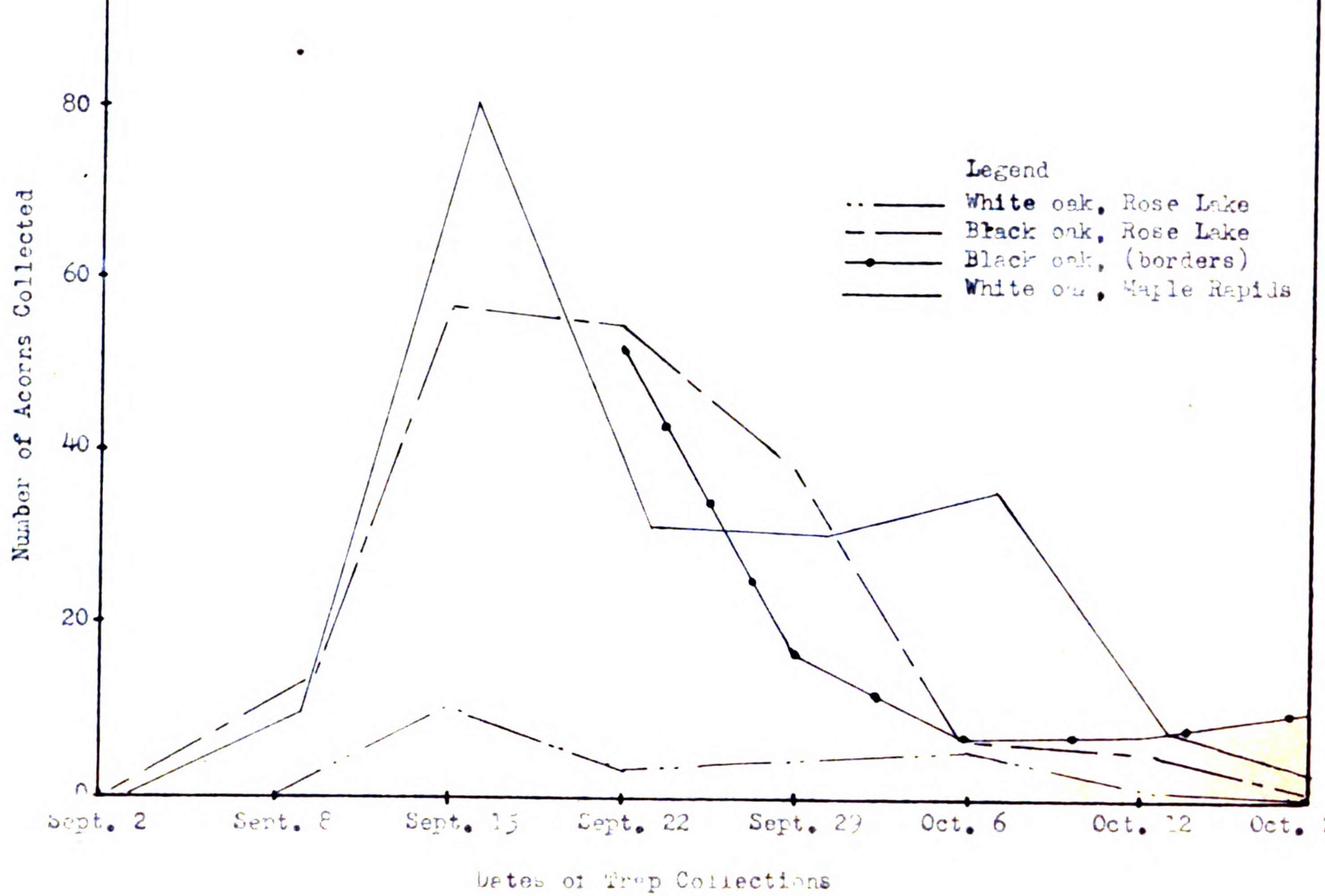


Figure 4. Period of Acorn Fall Determined From Trap Collections: Counts Exclusive of Small Size Acorns

The peak for black oak was protracted into a 3 week period, September 8 to 29. Although the data are limited, border black oak fall appears similar to that for interior trees.

The fall period for mature acorns is modified by several factors, among which are climate (abscission formation), wind, insect damage, and animal activity. Cypert and Webster (1948) found a wide range of dates of acorn dropping for individual trees as well as seasonal variations. Downs and McQuilkin (1944) stated that the period of drop tends to lengthen with larger crops but 75 percent of the drop, whether heavy or light, occurs in about a month. Poorly developed, wormy acorns begin to fall about a month earlier (Toumey and Korstian, 1947). This was particularly evident for red oak during the current year.

Korstian (1927) and Wood (1938) state that acorns are normally shed somewhat in advance of the cups. However, the weekly trap data of this study revealed close correlation between acorn and cup fall. Animal activity may have heightened the cup fall.

Composition of the 1952 Acorn Crop

Analysis of the acorn crop is limited to trap collection data presented in Table 6. The most striking

Table 6

Composition of the 1952 Acorn Crop, Based on Trap Collections, September 15 to October 24

Category	Rose Lake		Maple Rapids		
	White Oak	Black Oak	Black Oak*	White Oak	Red Oak
	Percent of Total**	Percent of Total	Percent of Total	Percent of Total	Percent of Total
Average Size Acorns	52.6	63.5	65.1	57.3	50.0
Sound	0.0	9.5	0.0	21.8	14.3
Damaged	100.0	90.5	100.0	78.2	85.7
Insect	80.0	64.3	63.9	61.3	57.2
Animal	20.0	20.0	17.7	10.5	14.2
Fungi	0.0	6.2	18.4	6.4	14.3
Cups	7.9	26.5	19.8	18.9	28.4
Small Size	39.5	10.0	15.1	23.8	21.4
Totals	100.0	100.0	100.0	100.0	100.0

*Six border trees, Woodlot 1
**Values for sub-categories represent a percent of the total average size acorns collected

feature of the crop was the uniformly high incidence of damage. This ranged from 100 percent for Rose Lake white and border black oaks, to 78.2 percent for Maple Rapids white oak. Conversely, sound, average size acorns were almost non-existent. Insects were largely responsible for the crop destruction. This was determined by actual cutting tests of collected acorns. Larval activities were noted in 80.0 to 61.3 percent of the white oak acorns, and in approximately 64 percent of all black oak. The low incidence (57.2 percent) for red oak appears incongruous with general observations, but may be due to the low numbers of the sample.

Degree of insect infestations apparently varies considerably between species, locale, and perhaps year and size of crop. Korstian (1927) reported an average of 18 percent insect damage for 4 species of oak in the southern Appalachians. Incidence was highest in black oak (27.7 percent) and lowest in white oak (10.6 percent). According to Kautz and Liming (1939) the 1937 Missouri acorn crop was 98 percent defective, of which 67 percent was attributable to insects. Downs and McQuilkin (1944) found insect damage to average 30 percent for all oaks, and believe that species differences are due to chance.

Linduska (1950) reported a noted species preference by insects for Rose Lake oak during 1941. The incidence was highest in black oak (81 percent), followed by white oak (67 percent), and only 7 percent for red oak. His assertion that the high tannin content of red oak may prove distasteful to insects is not substantiated. The possibility exists that low acorn production increases the incidence of insect infestation.

Three main groups of insects are known to damage acorns; these are (1) nut weevils or curculios, (2) moth larva, and (3) gall forming cynipids (Korstian, 1927). Curculios of the genus _Balaninus_ appear to be the most destructive. As many as 4 large larvae per acorn were removed from white oak acorns collected at Rose Lake.

Although insects often totally destroy acorns, 72.3 percent of the Maple Rapids white oak acorns damaged had more than one-half the endosperm intact. It was substantially lower (46.0 percent) for interior black oak. Germination of weeviled acorns is poor, particularly if the embryo has been damaged. The percentage of normal seedlings developing from weeviled acorns is practically negligible (Korstian, 1927).

Animal damaged acorns from trap collections represent tree foraging activities. This would include squirrel and bird harvesting but not that of chipmunks. In many instances great quantities of acorn and cup fragments were collected from the traps which could not be evaluated. The variation in incidence of damage was remarkably uniform between species and areas. It ranged from 20.0 percent for interior black oak to 10.5 percent for Maple Rapids white oak. Animal damaged acorns are probably those dropped or collected by animals but found to be worthless as food. Sound, or slightly damaged acorns are either consumed in the tree, dropped to the ground intact, or carried away. The amount of acorns removed from trees is indicated from empty cup tallies. For example, 23 damaged acorns were tallied for black oak, but 48 cups were collected --- 34 percent of the average acorn crop was not retrieved by the traps. Forty percent of the Maple Rapids white oak were similarly affected. Birds, as well as squirrels, may have been responsible.

The determination of acorn utilization by animals based upon open quadrat data has been commonly attempted (Korstian, 1927; Wood, 1934, 1938; Downs and McQuilkin, 1944, Cypert and Webster, 1948). In practice, the number of empty cups found (not ordinarily carried away) remaining in the quadrat has represented the amount of animal depredation. By this method Korstian (1927) found animal utilization to average 68 percent for 4 species of oak. A high deer and mouse population was responsible. Wood (1938) noted that as high as one-half of the newly fallen chestnut oak crop was removed by squirrels; Pine mice were responsible for destruction of acorns during winter. Downs and McQuilkin (1944) reported a 24 percent average utilization of acorns by sciurids, mice, and deer; the latter were the worst offenders. Cypert and Webster (1948) observed bird depredations amounting to 13.8 and 12.8 percent of the entire water and willow oak crop in Arkansas, in 1939 and 1940.

Theoretically, the number of trapped acorns is expected to be greater than that for ground quadrat collections. In this study, however, twice as many damaged acorns were noted for open plots than for traps, equaling 23.2 to 43.7 percent of the total average size quadrat acorns counted. Empty cup counts were obviously also distorted. Thus, black oak cups were 2.4 times as abundant in open quadrats as in traps. The greater amounts of acorns and cups within the quadrat was not expected, their true relationships are conjectural;

therefore adequate analysis of animal utilization from open quadrats is impossible. The use of this method may be considerably more complex than has been previously believed. The problem is discussed further on page 51.

Damage from fungi was generally of minor importance (Table 6), ranging from 0 to 18.4 percent. It averages about 6 percent of the crop for interior black oak and Maple Rapids white. Incidence of fungi within acorns may be related to insect damage, because fungi spores may conceivably enter through ovipositor scars. Korstian (1927) found a very low incidence of fungus (Penicillium) in newly fallen acorns although it averaged 10 percent as a mortality factor during germination. Kautz and Liming (1939) reported a 16 percent acorn decay but did not specify the cause.

Small size acorns result from a cessation of growth development. The highest incidence occurred in Rose Lake white oak (39.5 percent) and appears correlated with the crop failure, suggesting a lower limit of physiological condition. It was also high for Maple Rapids white oak (23.8 percent), but only 10.0 and 15.1 percent for interior and border black oak, respectively. Climatic conditions may account for these species differences.

Variations in Trap and Quadrat Collections

Trap-pairs

The variations existing between trap-pair collections (Table 7) represents differential crown sampling due to trap position. The higher totals of a pair may be correlated with greater production of the denser crown area sampled, but cannot be stated with certainty. The use of a single trap per tree (Cypert, 1951) may be justified since the differences between traps is often small. For high producing trees, the collection differences vary about 10 to 25 percent between members of a trap-pair.

Trap-quadrat pairs

The differences noted between complimentary trap and quadrat collections in Table 7 are not readily explained. As previously mentioned, open quadrats have been used to determine the degree of animal utilization. The validity of the data is based upon the belief that acorn and cup fall collections are normally distributed. This was not true for the present study. The higher quadrat counts may be explained as follows:

(1) Some acorns falling onto the trap periphery rebounded over the trap edge, thus lowering the collection counts. Quadrats lying in close proximity to a trap edge

Table 7

Number of Acorns and Cups in Traps and Ground Quadrats,
Collected September 2 to October 24*

		Trap and Quadrat Number (Pairs)																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals
		Number of Acorns and Cups																				
Rose Lake White Oak	Trap	0	2	0	0	1	2	0	0	0	1	1	0	6	1	0	2	3	0	1	2	22
	Quadrat	3	4	0	0	3	4	1	0	0	0	2	1	2	2	1	1	1	1	1	2	29
Black Oak	Trap	0	2	10	6	11	9	1	2	2	4	4	1	33	28	0	2	2	6	17	23	163
	Quadrat	17	8	53	23	21	12	2	2	12	7	3	5	22	37	0	0	4	5	23	23	289
Black Oak** (Borders)	Trap	0	2	2	0	4	0	14	9	46	9	3	1	-	-	-	-	-	-	-	-	90
	Quadrat	0	2	1	0	5	3	16	9	48	18	20	23	-	-	-	-	-	-	-	-	145
Maple Rapids White Oak	Trap	3	5	57	48	2	3	2	2	2	1	2	2	24	18	5	4	0	1	1	7	189
	Quadrat	6	14	76	45	0	1	0	1	6	2	2	0	33	27	11	2	1	1	0	6	234

*Exclusive of small size acorns
**North border 1 to 6, South border 7 to 12; odd number units were on border side

may have received some of these acorns, raising their counts. Trap tests revealed a low probability for this phenomenon.

(2) The quadrats may not have been entirely cleared of previous acorn and cup fall due to the heavy leaf litter often present on the plot area. The litter was not excessively disturbed in the original search; acorns present may have been subsequently found and recorded.

(3) Animal activity may have abnormally affected the normal distribution of acorns on the ground. A high chipmunk population existed in woodlot 6. Several dens were located near or within the quadrats under high producing black oaks. High densities of squirrels and mice were noted for Maple Rapids. The ground beneath some white oaks was often a labyrinth of mouse tunnels. The feeding and caching activities of these small animals may have invalidated the quadrat counts under these trees because of local acorn concentrations.

The possibility that trap collections were rifled by animals is remote. Experimentation with sound, marked acorns during the study proved the traps to be almost completely animal proof during the weekly periods. Marked acorns within the open quadrats quickly disappeared or were broken by animals. The fact that Rose Lake white oak was comparatively immune to the phenomenon indicates that animal activity was the major cause of the higher plot counts. The animals were obviously not interested in the low acorn production of this species.

Acorn Production Estimation from Crown Acorn Counts and Trap Collection Ratios

A method was devised for estimating individual tree production from the relationship of total sample tree acorn counts and trap collections. The calculations of total tree production retrieved by trapping are presented in Table 8. Percentage of trap returns are more variable, and usually higher, for low producing trees. The percentage of returns for high producing trees is remarkably uniform, varying from 3.4 percent for black oak number 10, to 5.3 percent for border black oak number 16. The low percent of the former tree may be due to its narrow, conical crown form. For the 5 interior black oaks the range is 3.4 to 6.7 percent and averaged 4.0 percent. South border oaks average 5.5 percent trap returns and vary from 3.8 to 6.5 percent. Maple Rapids white oak traps retrieved 3.8 to 5.3 percent of the total counted production, and averaged 4.6 percent.

Table 8

Proportion of the Acorn Crop Determined
by Tree Counts to that Measured by Trapping*

Rose Lake: Tree Number	White Oak 1	7	10	Totals	Black Oak 1	6	8	9	10	Totals
Tree Counts: Number of Acorns	74	98	36	208	39	25	30	138	1,188	1,420
Trap Collections: Number of Acorns	2	7	3	12	2	5	2	8	40	57
Percent Retrieved by Traps	2.7	7.1	8.3	5.7	5.1	5.0	6.7	5.8	3.4	4.0

Maple Rapids: Tree Number	White Oak** 2	5	7	8	Totals	Black Oak (Border)+ 15	16	17	Totals
Tree Counts: Number of Acorns	1,363	19	459	80	1,921	352	1,044	104	1,500
Trap Collections: Number of Acorns	62	1	22	3	88	23	55	4	82
Percent Retrieved by Traps	4.5	5.3	4.8	3.8	4.6	6.5	5.3	3.8	5.5

*Exclusive of small size
**Counts and trap data after September 15
+South border of woodlot 1

The data can be used for estimating total tree production from average trap return percentages. This is obtained by dividing trap collections by the average percent total trap returns. The estimated production in Table 4 was obtained by this method. For example, the total trap collections for black oak number 7 amounted to 61 acorns, this, divided by .04 (the 4 percent average trap returns), equals 1,525 acorns. Deviations from true production are expected to be compensatory. Whether ratio changes will occur following high production cannot be stated; however, similar relationships should be operative. Although crown counts are difficult to obtain, the ease and accuracy with which production estimates are obtained by this technique warrants its use.

Detailed data on acorn production may not be needed. Often, general observation indices, depicting year-to-year trends, are sufficient. The data from Table 5 result largely from ground observation of acorn fall, particularly for border and isolated trees. Relative abundance of cups, acorn fragments, and weeviled acorns (not ordinarily removed by wildlife) provided the basis for the high, medium, and low categories. Annual resampling of selected trees, checked at weekly intervals during acorn fall, should provide adequate indices to acorn production and animal utilization. A similar mast index has been devised and is currently in use in West Virginia (Uhlig and Wilson, 1952).

VI. POPULATION SIZE AND ACORN UTILIZATION OF CERTAIN SMALL MAMMALS

Observations during September indicated an abnormally high eastern chipmunk (Tamias striatus rufescens)[1] population was present in Rose Lake woodlot 6. Signs of high densities of white-footed mice (Peromyscus leucopus noveboracensis) were also noted for Maple Rapids. Since the acorn crop was poor, the author believed that severe competition for acorns would develop during the fall between these species and other mast-eating game animals. In order to determine the possible extent of this food competition, a line-trapping study for the estimation of chipmunk population size was conducted at Rose Lake during October. In addition, an acorn feeding experiment was devised to test the consumption and preference of acorns by chipmunks and mice. The results of these studies were intended to provide data upon which an analysis of acorn competition could be made.

Materials and Methods

Cooperation was obtained from the Rose Lake Station staff for the collection of chipmunk data during the

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[1] Common and scientific names of mammals are according to Mammals of Michigan, Burt (1948).

normal course of pre-hunting season animal population studies. Population estimates are derived from live-trapping data through the use of tagged-untagged ratios, or from hunting season kill-ratios.

A total of 12, permanently stationed box traps, spaced one to the acre in grid pattern, were operative in woodlot 6 during a 10 day period, October 6 to 17, for a total of 120.5 trap days. The traps were checked twice daily. All animals captured were ear-tagged, the weight, age, and sex noted, and released. Ear corn and dried herring were used as bait. The weather during this period was mostly clear and cool.

The acorn feeding experiment began on October 18. A total of 5 chipmunks and 4 mice were captured in box-traps and confined in cages at the Michigan State College animal house (Table 10). The chipmunks were confined in experimental rat cages. The cages measured 18 inches on the side. One chipmunk was later transferred to a commercial type squirrel cage, complete with rotary exerciser. The mice cages were cylindrical, 5 inches high and 8 inches in diameter. Wood shavings and cotton batting were provided for nesting. Water was available at all times. The animals were examined every day and fed periodically, depending upon the quantity of food remaining. Acorns were the only food provided during the study. An attempt was made to feed only well-developed, sound acorns; however, this was not always possible. Four species of acorns were collected. These were placed in quart jars and subjected to room temperature for several days. At the end of this period almost all weevil larva had emerged from the acorns. Acorns without emergence holes were checked, and fed to the animals.

The animals were kept at room temperature, ventilation and light were provided by several windows. Except when fed, the animals were not disturbed. Although the cages were small the animals appeared healthy and vigorous. Examination of several sacrificed specimens at the end of the study did not reveal symptoms of malnutrition. As late as November 15, none of the chipmunks showed signs of torpidity.

Results and Discussion

Chipmunk Population Estimate

Results of the live-trapping program are presented in Table 9. The high frequency of chipmunk capture reveals the relatively greater abundance of this species to other sciurids in the woodlot.

Table 9

Results of Live-Trapping at Rose Lake Woodlot 6 During October 6 to 17*

Species	Number of Individuals			
	New Records	Previous Records	Recaptures	Total
Eastern Chipmunk	16	5	25	46
Red Squirrel	5	-	-	5
Southern Flying Squirrel	1	1	-	2
Fox Squirrel	2	3	1	6

*Twelve traps operating for 205.5 trap days

Estimation of the chipmunk population, calculated from tagged-untagged ratios (Hayne, 1949), proved unsatisfactory. The highest estimate obtained was 28 chipmunks, or 2.3 animals per acre for the 12-acre woods. This density appeared incongruous with field observations, a much higher population was indicated. In lieu of the above estimate, a population size of approximately 7 chipmunks per acre was ascribed to the 6-acre portion of the woodlot. This was believed to be the best estimate of the actual density prevalent on the area, and was not considered excessive. Bole (1939) reported a high density of 8.7 per acre for upland forests in Ohio during 1935. Burt (1940) found populations of 2.4 and 3.6 per acre in two oak-hickory woodlots in southern Michigan, but believes September populations may average 4 to 5 per acre after the second litter appears above ground (1948). Linduska (1950) observed densities of 2.0 to 2.5 chipmunks per acre for a 23-acre woodlot during a low population period.

The cause of this high density is not clear. However, approximately three times as many chipmunks were handled during the 1952 trapping period as in 1951, indicating an "irruptive" type fluctuation. The phenomenon did not appear to be restricted to the Rose Lake area, but was more widespread.

Estimates of other sciurids was not attempted, but observations of them deserve mention, since they are also important competitors for acorns. The six red squirrels (*Tamiasciurus hudsonicus loquax*) trapped may represent a minimum population of one per 2 acres. Linduska (1950) reported a maximum of 2 per acre for woodlot 6 during 1940. During this period, flying squirrel (*Glaucomys volans volans*) densities were one per acre for this woodlot; however, Linduska expressed doubt as to efficiency of the box-traps. Burt (1948) states that groups of 20 or more may band together in a single den during winter.

Population data were not collected for white footed mice. High densities were believed to exist in Maple Rapids. Numerous burrows, and other signs of activity, were noted. Mice were frequently captured in box-traps during a preliminary study. Burt (1940) found mice populations to vary from a spring low of 3.0 per acre to 10 or 13 per acre in November. Linduska (1950) reported a density at 7.6 mice per acre in woodlot 1 during October.

Of the mast-eating game animals, fox squirrels (*Sciurus nigra rufiventer*) are probably most directly affected by acorn competition. Significantly, fox squirrel populations were low in woodlot 6 during 1952. Less than one squirrel per two acres was removed from this woodlot during the hunting season, although gun pressure was high. All other sciurids were probably near peak densities. Linduska (1950) found similar inverse trends operating during his 1940-42 Rose Lake study. Although food competition may be a limiting factor, there is evidence to indicate a 4-year cycle of abundance for Rose Lake fox squirrels.[1] The fox squirrel population at Maple Rapids was believed to be high. Many tree dens and leaf nests were present in this woodlot and fox squirrels were commonly seen during the study. One hunter interviewed reported killing 19 squirrels during the 1951 hunting season - almost 1 squirrel per 2 acres. The population for this woods is probably between one and two per acre. Chipmunks were not present in the woodlot, although flying squirrels were noted.

Acorn Feeding Experiments

The data obtained from this study, presented in Table 10, are of considerable importance since comparable information is lacking. During the 98 chipmunk days

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[1] Oral communique with Dr. C. T. Black.

Table 10

Species and Number of Acorns Fed, Total, and Daily Average Food Consumption of Captive Chipmunks and White-Footed Mice

			Species and Number of Acorns										
	Feeding		Red Oak		White Oak		Black Oak		Scarlet Oak*		Totals		Daily
Animal	Period	Days	Fed	Eaten	Fed	Eaten	Fed	Eaten	Fed	Eaten	Fed	Eaten	Average
Eastern Chipmunk	Oct.18-Oct.20	2	6	3	6	6	6	5	-	-	18	14	7.0
	Oct.19-Nov.15	28	48	48	57	57	57	57	30	30	192	192	6.8
	Oct.24-Nov.15	23	29	28	41	41	41	41	30	30	141	140	6.1
	Oct. 24-Nov.15	23	31	29	41	41	41	40	30	27	143	137	6.0
	Oct.25-Nov.15	22	30	5	41	41	41	41	30	30	142	117	5.3
	Totals	98	144	113	186	186	186	184	120	117	636	600	6.1
White-footed Mouse	Oct.15-Oct.19	4	3	0	3	2	3	3	-	-	9	5	1.2
	Oct.18-Oct.19	1	3	0	3	1	3	1	-	-	9	2	2.0
	Oct.19-Nov.15	28	15	2	21	21	20	20	12	6	68	49	1.8
	Oct.19-Nov.15	28	15	4	22	20	20	20	12	10	69	54	1.9
	Totals	61	36	6	49	44	46	44	24	16	155	110	1.8

*Sole diet Nov. 10 to 15 (5 days)

of feeding, the average consumption was 6.1 acorns per individual per day. Slight variations are noted, the high 6.8 daily average of one chipmunk is probably the result of greater energy expenditure, since this animal had use of the rotary exerciser cage. The lowest individual average consumption (5.3 acorns per day) resulted from a distaste for red oak acorns rather than a lower food requirement. The data for red oak utilization are misleading. It was soon evident that acorns of this species were not being eaten. From November 5 to 9 no additional acorns were fed in order to encourage consumption of accumulated red oak acorns. These were subsequently eaten, except as noted. No ill effects were observed. Baumgras (1944) reported that 2 of 3 fox squirrels died within 10 days when fed this species. He believes the high tannin content of red oak is unpalatable for fox squirrels. The tannin content appears to vary with region of acorn origin, according to Korstian (1927), and may often be considerably lower than that of white oak. Urban fox squirrels greedily consumed red oak acorns, even though other foods were available. Baumgras noted a slight loss of weight (2.6 grams per day) for test squirrels fed red oak acorns, but the loss was greatest (3.2 grams per day) with a corn diet.

All white and black oak acorns fed were readily consumed. Although both species were sound and well-formed, white oak acorns were approximately twice as large as the black. Observations during feeding indicated white oak acorns were preferred. They were invariably eaten first, although both were supplied in equal numbers. Baumgras (1944) believes that the higher utilization of this species by fox squirrels represents a lower food value for white oak.

During the last 5 days of the experiment one lot of 30 scarlet oak acorns (<u>Quercus coccinea</u>) were fed to each chipmunk. All but 3 of the 120 acorns fed were consumed during this period - 5.8 acorns per day per chipmunk - only slightly less than maximum consumption.

Average consumption for mice was 1.8 acorns per day, and was remarkably constant (Table 10). All but two white, and all black oak acorns fed were eaten. White oak acorns were eaten first, but preference may have been due to the softer testa of this species. Of the 12 scarlet oak acorns fed, consumption was maximum (2.0) for one individual, but not for the other (1.2 acorns per day). The latter may represent availability of uneaten food. Red oak acorns presented a major problem because of their large size. About half of the number fed were breached, however, and one-fourth to one-third of each endosperm eaten. In feeding, a small hole was chewed at the base of the acorn and gradually enlarged to allow extraction of endosperm fragments.

Hamilton (1941) states that under natural conditions, adult deer mice eat about 6 grams of food daily. This is equivalent to approximately 2 white oak acorns.

Effects of Competition for Acorns

The significance of the population and food habit studies lies in analysis of the possible deleterious effects imposed upon mast-eating game animals by competing small mammals. Oak regeneration is also directly related to acorn utilization by these animals, and may often be severely curtailed (Korstian, 1927; Wood, 1934, 1938; Downs and McQuilkin, 1944; and Baker, 1950).

Acorns provide substantial food for numerous wildlife species and therefore rate a position at the top of the wildlife food list, not only because they are a preferred food item, but because they constitute a staple fall and winter food for many game animals (Van Dersal, 1938, 1940; Martin, et al., 1951). Acorns are not always abundant or available to game animals. During a poor crop year the lack of food may prove critical. Allen (1943) noted a marked fox squirrel mortality and debilitation following an oak crop failure in Allegan County, Michigan. Linduska (1950) observed a food shortage existing in Rose Lake woodlots during an acorn failure in 1940, but not the two following years. He believes no marked incompatability exists between the woodland rodent species, but noted that all were in direct competition for the same foods, and except for chipmunks, for the same nesting sites.

A food shortage may have developed in woodlot 6 during 1952-53. Assuming a chipmunk and mouse density of 7 per acre, the total number of black oak acorns consumed within 60 days after acorn fall is calculated at 3,275 sound acorns per acre, or approximately 1/4 bushel. The average production for black oak was 408 acorns per tree, or 4080 acorns with ten trees per acre. Of this total, only 50 percent (2040) were usable as food, due to damage. Acorn caching activities effectively eliminates food otherwise available to game animals. The caching propensities of chipmunks and mice are well-known. Burt (1940) states that "the storage of food is one of the chief daily activities of eastern chipmunks. If a supply of food is located they will work tirelessly carrying it away to their subterranean granaries." Allen (1943) believes the importance of mice as food competitors of fox squirrels have not been sufficiently recognized.

Acorn utilization and caching by red and flying squirrels, and passarine birds, is also significant and adds to the deficit of food. An indication of this is noted from the high incidence of animal damaged acorns (20 percent) and empty cups (34 percent) trapped from black oak trees, as previously reported.

Fortunately, small mammal populations often fluctuate violently and low densities are common. The most serious competition results from concurrent high rodent densities and poor mast years. High rodent populations during a high yield year are probably not inimical to oak regeneration, because the total acorn crop may not be consumed. The basic causes of rodent population cycles are poorly understood, but may be due partly to food supply. They do not appear to be synchronized with seed-year cycles of forest trees, since the latter are very irregular (Baker, 1950). Whether the apparent

3 to 4 year cycle of fox squirrels coincides with that for acorns is not known.

The tremendous destruction wrought by insects further delimits the amount of acorn food available. Linduska (1950) believe that weevils (Balaninus sp.) are the most serious competitors for the acorn crop. This was particularly true during 1951. Many of these acorns are suitable as food, although they may not be stored. Some animals may relish the larva itself. Urban fox squirrels readily consumed weeviled acorns, if the endosperms were not excessively damaged.

The total effect of acorn competition is considerable and may regulate animal populations through limiting range carrying capacity. Rodents, and the lesser-sciurids have value as insect eaters, and as buffer animals for other game species. The buffer value of hibernating chipmunks is probably negligible, however. These animals may be controlled by encouraging natural predation. Unfortunately, little can be done at this time to reduce insect damage.

SUMMARY

An investigation of some factors influencing production and utilization of acorns, for two upland oak-hickory woodlots at Rose Lake and Maple Rapids, in Clinton County, Michigan, was conducted during the fall of 1952. The areas differed widely in plant composition, land-use, and soils. Forty trees were chosen in the two woodlots for an investigation of the size and nature of the acorn crop. Twenty of these trees were selected for study of insolation effect on crown development and acorn production.

1. The data revealed that acorn production is largely confined to the tops of trees in closed stands. The production differences are not correlated with number or size of limbs.

2. Greater quantities of seed were found on south facing limbs, followed by west, east, and north. The lower limbs were not similarly affected.

3. Acorn production of border trees was similar to that of interior trees. South border trees had the greatest production. The bulk of the acorns are produced by upper crown limbs.

4. The 1952 acorn crop was low, and failed entirely for Rose Lake white, and Maple Rapids red oak. Production of acorns was not consistently correlated with such characteristics as crown size, bole diameter, or growth rate, although the larger trees usually produced the largest acorn crops.

5. Acorn yield of open-grown, or border trees, was neither greater nor more frequent than for forest-grown trees.

6. The bulk of the acorns fell during a three-week period, September 8 to 29. The fall was greatest during the first week of this period.

7. A high incidence of acorn damage was recorded. It ranged from 100 to 78.2 percent of the crop, depending upon species and site. Insect damage, mainly by acorn weevils, was largely responsible, contributing 80.0 to 61.3 percent of the damage.

8. Animal damage to tree acorns accounted for 20.0 to 10.5 percent of the average-size acorns trapped; 34 to 40 percent more may have been removed from the trees as noted from empty cups.

9. Differences in trap-pair collections resulted from sampling of unequal foliage densities. Trap-open quadrat pair variations were probably due to local acorn concentrations by small mammals.

10. Acorn traps retrieved 4.0 to 5.5 percent of the total production counted on sample trees. An acorn estimation technique was devised from this data.

11. An estimated density of 7 chipmunks per acre was ascribed to the 6-acre study area of woodlot 6. This was based upon observations, since live-trapping data failed to produce satisfactory results.

12. According to an acorn feeding experiment devised for captive chipmunks and white-footed mice, the average consumption for chipmunks was 6.1 acorns per day; it was 1.8 per day for the mice. Of the four acorn species fed, red oak was the least preferred.

13. An acorn shortage may have developed in woodlot 6 during the fall of 1952. Consumption by chipmunks and mice is presumed to have caused a deficit over the amount of acorns produced.

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