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THE importance of oak in the forests of West Virginia has led to a study of factors affecting natural regeneration of oak in northern West Virginia. This study, initiated in 1953, is providing results which aid in the better understanding of natural establishment of oak seedlings, and which should lead to improved silvicultural methods for managing oak stands.

The determination of the amount of reproduction, by species, under oak stands was the first phase completed (Tryon and Carvell 1958). This was followed by a report of species of shrubs and herbs common to the different oak sites (Carvell and Tryon 1959). The next phase completed pertained to the importance of environmental factors including soil, topography, and climate on the abundance of oak regeneration beneath these oak stands (Carvell and Tryon 1961).

During the course of the study, acorns were collected and examined to determine acorn production of northern red oak (*Quercus rubra* L.) and white oak (*Quercus alba* L.) as well as amount and types of damage to acorns of the two species. The results are presented in this bulletin.

Conditions and Methods

In mixed oak stands, 14 red oaks and 14 white oaks of seed-bearing age were selected and used for the determination of acorn production and damage. The crown class of each oak selected was dominant, and the crowns were not crowded by other trees. Characteristics of the individuals selected are presented in Table 1. These 28 oaks are the center trees of the permanent plots described by Tryon and Carvell (1958) in their evaluation of regeneration under oak stands.

Two seed traps and two ground quadrats were established under the crown of each tree in the late summer of 1954. The seed traps (Figure 1) were one-quarter milacre in area and of treated cardboard as described by Easley and Chaiken (1951). Hardware cloth was placed over the opening in the bottom so that even the small immature acorns would be retained; and 1-inch mesh chicken wire was placed within the traps to keep out rodents. The ground quadrats were of the same area as the traps (one-quarter milacre), and each corner was marked with pipe. Before the first collection in 1954, all acorns were removed from the ground quadrats with a minimum of disturbance to the humus.

Table 1. Northern Red Oak and White Oak Characteristics (28 Plot Trees)

	Species	D.b.h. (Inches)	Age (Years)	Crown Diameter (Feet)
Mean	Northern red oak	24.6	102	44
	white oak	19.8	114	35
Minimum	Northern red oak	12.5	51	24
	white oak	12.5	58	17
Maximum	Northern red oak	38.0	160*	64
	white oak	31.6	230*	48

*These ages could not be determined accurately. However, they were included in calculating the mean ages.

Studies in the Missouri Ozarks indicated that the acorn drop is uniform within the horizontal projection of the oak tree crown, and is independent of the trap's distance and compass direction from the bole (Burns *et al.* 1945). Preliminary sampling in 1953 indicated a similar uniformity of acorn fall under the crowns of oak in West Virginia plots. Therefore a statistical procedure was designed for locating the traps and quadrats, but it was discarded in favor of a more random method because rocky soil and nearby oaks of the same species as the plot tree prevented placing the traps and quadrats as specified in the design.

Bi-weekly collections were made from the traps each fall, and one collection was made in mid-April from the ground quadrats. Recorded in each collection were: (a) mature acorns, (b) cups, and (c) immature acorns. Mature acorns were tallied as sound, damaged by insects, damaged by rodents, and damaged by other agents such as fungi. In addition, the number of acorns removed from the tree and from the ground by animals could be calculated from these data and the total acorn crop determined.

For certain phases of this work, analysis of variance, estimate of component variance, t-test, and simple and multiple regressions were used to test differences or relationships. Large differences, ranging from 0 to hundreds, occurred between tree-to-tree and year-to-year acorn counts. Accordingly, acorn count data were transformed by $\sqrt{x+1}$ for more efficient statistical testing. The arcsin transformation was used for statistical testing involving percentage values. This transformation,

FIGURE 1. Paired seed traps, each with an area of ¼ milacre, under a northern red oak. This tree is 60 years old, 20 inches d.b.h., and has a dominant crown 48 feet in diameter. It is one of the better producers of acorns.

used for percentages or proportions, gives greater weight to the lower values which have small variance (Snedecor 1957).

Results

Determination of acorn production and damage, using collection data from traps alone, or in combination with ground quadrats, has been made by several investigators. This procedure is the most practical method for doing such detailed work with many trees over a period of several years. However, the method is not entirely accurate. Gysel (1956) and Verme (1953) pointed out that seed traps provide lower acorn counts than the actual fall. However, since the results involve differences between species, or among trees or years, any discrepancy should be proportional; thus all comparisons would be valid.

MATURE ACORN PRODUCTION

The outstanding feature of acorn production was the variation found to exist among individuals within the species and among years. Such variation has been reported by Burns *et al.* (1954), Christisen

(1955), Christisen and Korschgen (1955), Downs and McQuilken (1944), Gysel (1956), and Wood (1934). The red oaks produced significantly more mature acorns than the white oaks, averaging 170 acorns per milacre of crown area per year for the five-year period compared with 96 for white oaks.

The average number of mature acorns produced per milacre of crown area, based on the horizontal projection of the crown of each individual tree, is presented in Figure 2. The differences among the red oaks were significant at the 5 per cent level, and nearly so at the 1

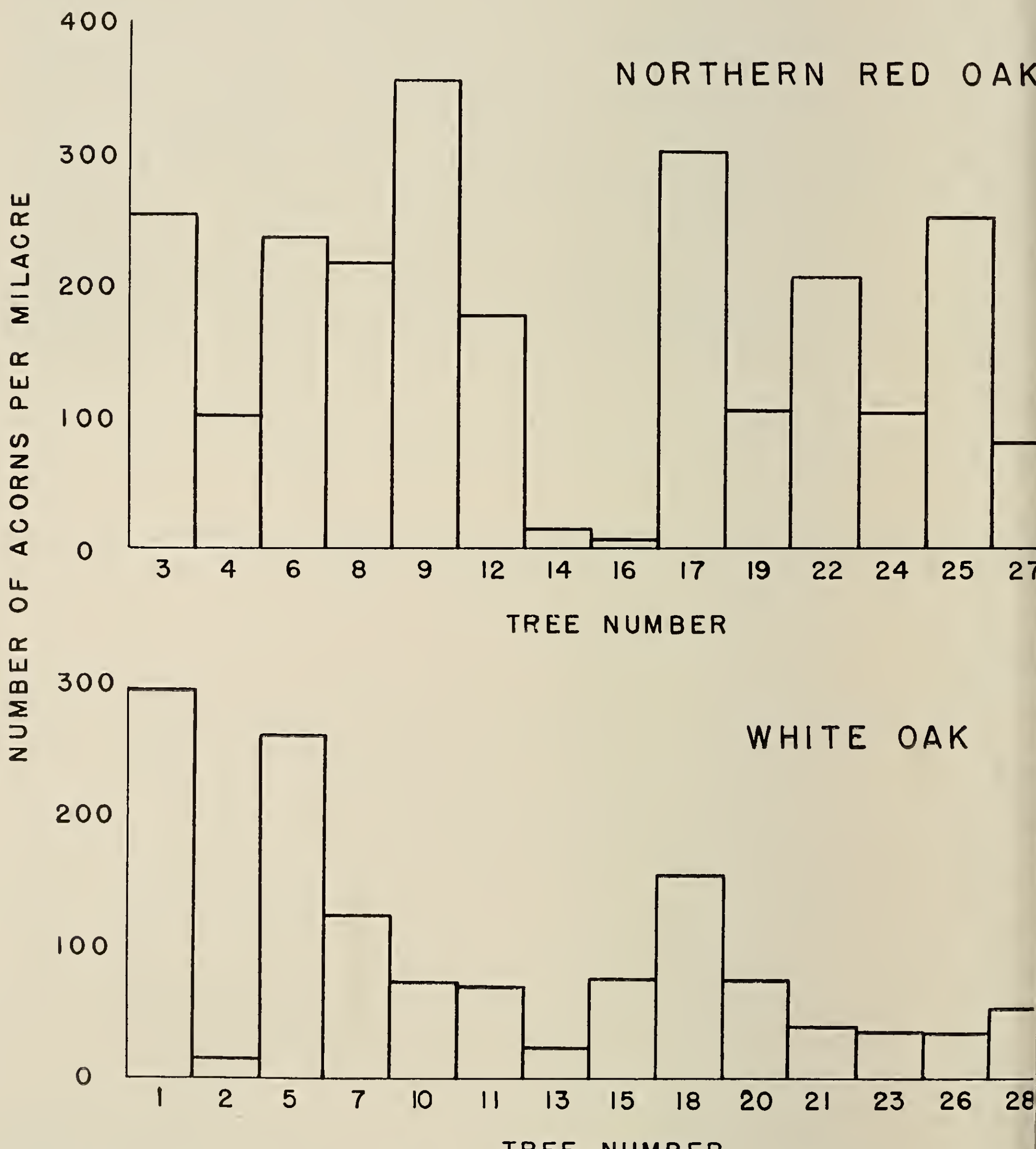

FIGURE 2. Production of mature acorns by individual trees within species based on a five-year average (1954-1958).

per cent level. The differences among the white oaks were significant at the 1 per cent level. Analyses of total acorn production per tree, after adjusting for crown area, indicated even stronger differences among trees; the differences were significant at the 1 per cent level for both species.

When individual tree data were evaluated by years, it became evident that those trees with the highest average production produced an acorn crop which exceeded the yearly average nearly every year, whereas the poorest producers consistently had small annual crops. This was true for both species and is considered to be an inherent characteristic of the individual tree. However, the individual white oak trees were the more consistent in producing heavy or light acorn crops.

Annual acorn production per milacre of crown area is shown in Figure 3. Differences in production among years for red oak were significant at the 5 per cent level. For white oak, differences among years were not significant, though nearly so at the 5 per cent level. Similar results were obtained for the two species when total acorn production per tree was used. Observations of the important oak species in this area for several years have led the authors to believe that at least one of the species produces a good crop of acorns nearly every year. The data presented and the observations on yearly acorn crops, however, are at variance with reports from other areas. In the southern Appalachians, five oak species studied by Downs and McQuilken (1944) were found to follow a common year-to-year trend in acorn production. In Missouri, similar trends were reported (Burns *et al.* 1954, Christisen 1955), although the latter writer pointed out that acorn crop failures of all species are unlikely.

The analyses reported above indicate a somewhat higher level of significance of differences in number of acorns among the individual trees than among years, especially for white oak. To compare further the variation in acorn production among trees and years, the estimate of component variance was used (Snedecor 1956). The results are presented in Table 2. The estimate of component variance was larger for trees than for years, and significantly so in three of the four tests. Furthermore, tree variance exceeded year variance to a greater degree in white than in red oak. Again, the results suggest the importance of inherent characteristics in the production of acorns, especially in the white oaks.

IMMATURE ACORN PRODUCTION

The number of immature acorns of both red and white oak made up 34.7 per cent of the total crop. Again, great variation was found

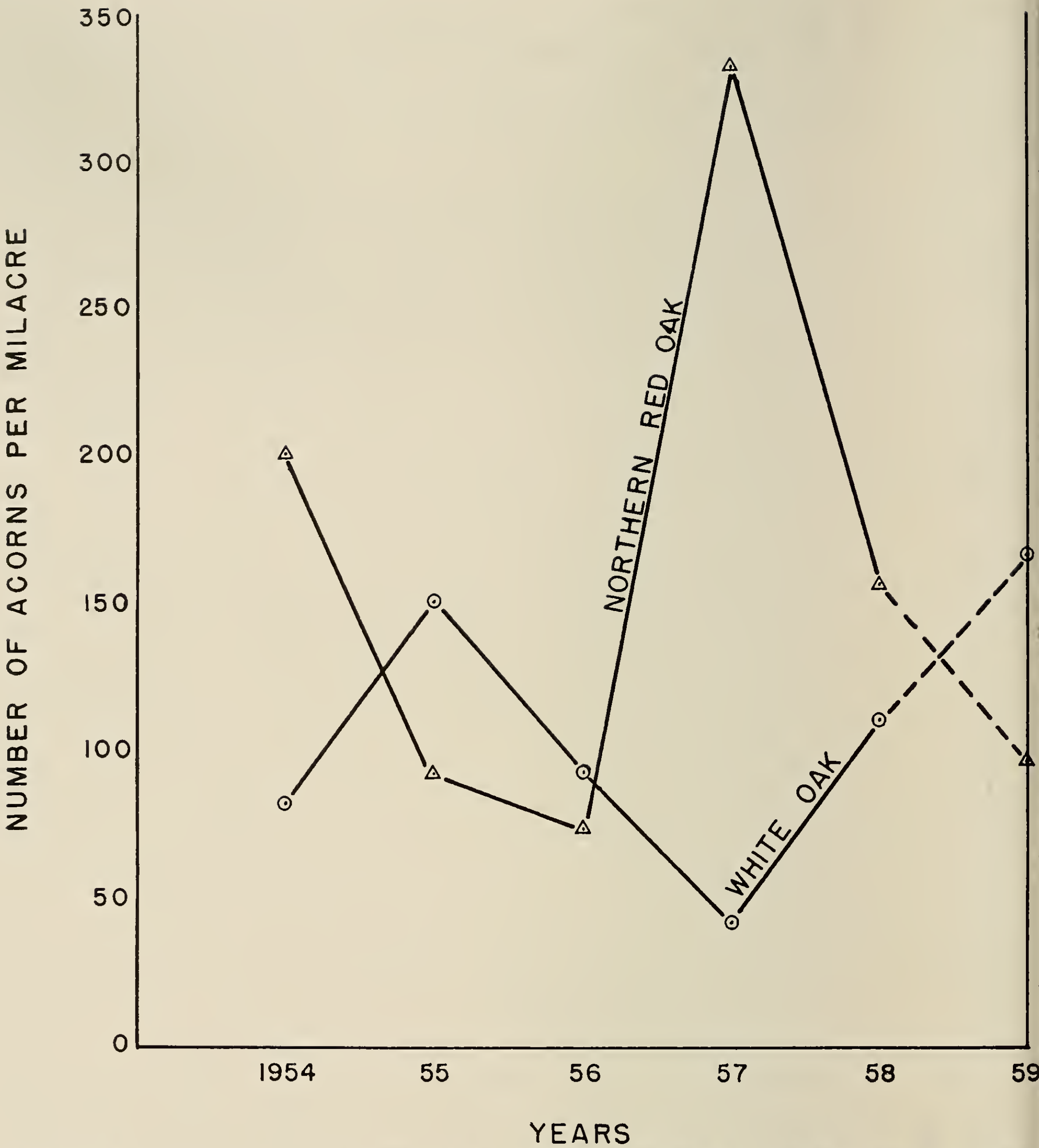

FIGURE 3. Production of mature acorns by species and years, based on average of 14 red oaks and 14 white oaks. (Amount for 1959 based on partial count.)

among trees and among years. The white oaks averaged 42.0 immature acorns per milacre of crown area per year and varied from 0 to 472. The red oaks averaged 99.4 per milacre and ranged from 0 to 588.

The number of immature acorns was positively related to the total number of acorns produced. Thus as the total number of acorns increased, the number of immature acorns increased proportionally. This relationship was significant at the 1 per cent level for both red and white oaks. A common trend line for the two species (Figure 4) was used as no real difference was found between the two trends when tested by multiple regression.

Table 2. Estimate of Component Variance Among Trees and Among Years in Acorn Production*

Species	Crown Area Basis	Variance		F	Level of Significance
		Among Trees	Among Years		
Northern red oak	Quadrats (0.5 milacre)	5.23	2.22	2.25	None
	Entire crown	893.44	240.87	3.71	5%
White Oak	Quadrats (0.5 milacre)	4.76	1.29	3.69	5%
	Entire crown	270.41	44.21	6.12	1%

*Transformed data were used.

Certain oaks tended to produce a relatively high percentage of immature acorns. Five red oaks were high producers 80 per cent or more of the years, and four white oaks were high producers 60 per cent or

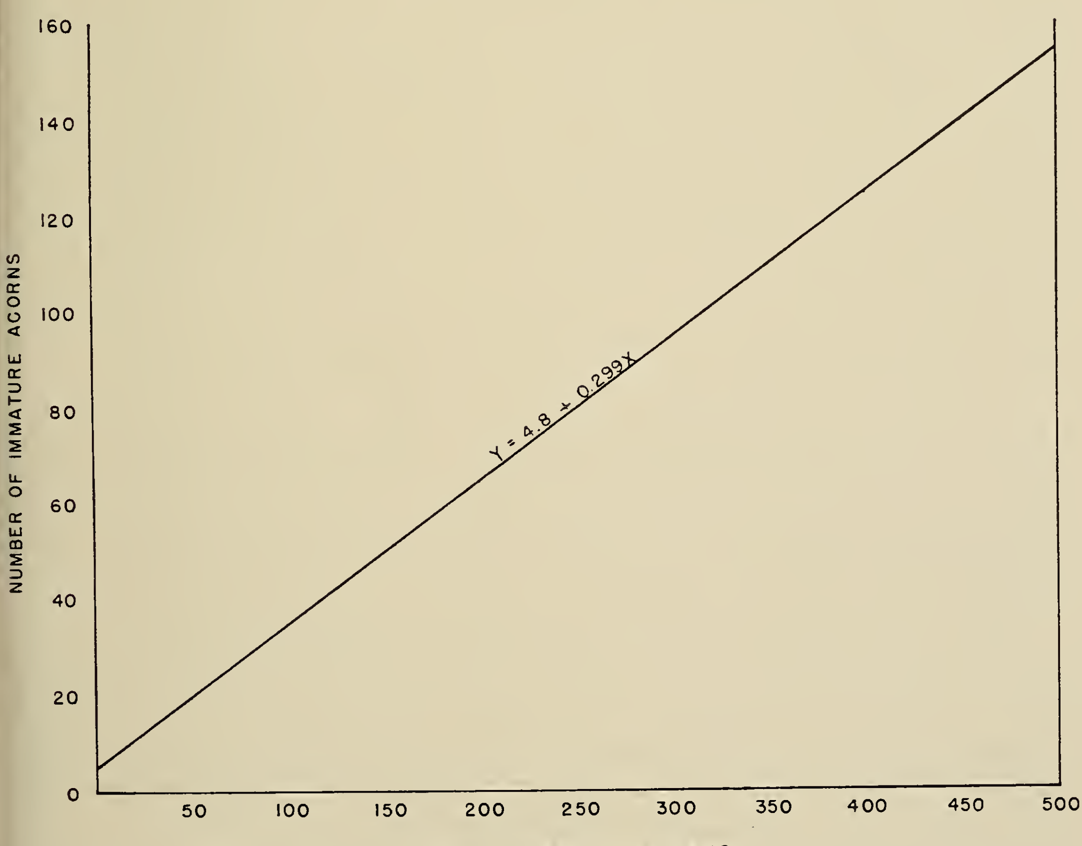

FIGURE 4. Relationship between immature and total acorn crop for combined red and white oaks.

more of the years. The oaks that produced a high percentage of immature acorns were not, however, among the best producers of total acorns. The production of relatively high amounts of immature acorns by certain oaks contributed to the variation in the relationship between the numbers of immature and total acorns produced, but not to the extent of reducing the significance of the trend presented in Figure 4.

The number of small developing acorns on the trees early in the summer has been used to predict the size of the mature acorn crop. Since a certain percentage of the young acorns developed into full grown acorns at maturity (an average of 65.3 per cent) regardless of crop size, the method appears sound. However, several trees should be sampled because of the tree-to-tree variability in acorn production.

FACTORS AFFECTING ACORN CROPS

Certain tree characteristics, site factors, and site quality were compared to size of acorn crops of individual trees to determine if any of these factors affected acorn production. This phase, however, was not planned when the study was originated.

The tree characteristics studied were crown area (horizontal projection), diameter (d.b.h.), and age. In general the size of the crop was more closely related to crown area than to diameter. Furthermore, the size of the red oak crop was more closely related to both crown area and diameter than was the size of the white oak crop. This poorer relationship for the white oaks may indicate that inherent characteristics govern acorn production of individual white oaks to a greater degree than they govern production of red oak acorns. The relationship of age to size of crop was studied, but not tested, because age could not be determined accurately for nine of the largest trees. Only a slight tendency appeared to exist for the production of larger crops by the older trees.

The site factors studied were aspect, per cent slope, position on slope, and periodic precipitation periods. No significant relationships were found between any of these site factors and acorn production, but this may have been the result of the similarity of these site factors among the plots.

The size of the acorn crop showed no strong relationship to site quality as determined by site index. Most noticeable was the relatively lower production of white oak acorns as compared to red oak acorns on the better sites (site index 75 to 80), whereas a closer relationship existed between acorn production of two species growing on areas having lower site qualities (site index 55 to 65).

Far more pronounced than the effect of site on acorn production was the variation in acorn production among individual trees on similar sites. An indication of tree-to-tree variation has been shown in Figure 2, although site and tree-size differences are not separated in the presentation.

In order to obtain more accurate indication of individual tree variation on similar sites, trees of each species which occupied similar sites and were comparable in diameter and crown area were studied in relation to size of acorn crop. Five white oaks, numbers 1, 5, 11, 13, and 20, averaged for the period 294, 260, 70, 22, and 78 acorns per milacre, respectively. Four red oaks, numbers 3, 4, 12, and 19, averaged for the period 252, 100, 176, and 102 acorns per milacre, respectively. The tree numbers are those used in Figure 2. Thus a considerable variation existed among individuals on similar sites, and the individual white oaks showed greater variation in acorn production than did the individual red oaks.

DAMAGE TO ACORNS

Heavy damage to acorn crops by agents which reduce the amount of sound acorns before they are able to germinate and produce oak seedlings is well known by foresters.

The excellent works of Downs and McQuilken (1944) and Korstian (1927) showed heavy damage to acorns by insects and animals. Similar results were obtained by Burns *et al.* (1954), Dalke (1953), Gysel (1957), Kautz and Liming (1939), and Verme (1953). Damage which exceeded 50 per cent of the acorn crop was reported by all investigators. Insects were usually more destructive than animals. Krajicek (1955), however, reported that animals destroyed 55 to 95 per cent of the acorns he had sown.

The amounts and types of damage to mature acorns are presented in Table 3. These results are based on an examination of nearly 10,000 mature acorns. Outstanding is the heavy damage (exceeding 80 per cent) by animals and insects combined. The greater loss, just over 50 per cent, was attributed to animals; this was followed by about a 30 per cent loss caused by insects. The loss of acorns from the trees and the ground attributed to animals is presumably somewhat less serious than the data in Table 3 indicate when the entire forest area is considered. Many of the missing acorns taken by rodents and birds would be buried or dropped in other parts of the forest where they could germinate and produce seedlings. The loss of 17.7 per cent of the acorn crop from the tree compares favorably with the results of Cypert and Webster (1948). They found that for water oak (*Quercus nigra* L.) and willow oak (*Quercus phellos* L.) birds removed 12.8 to 13.8 per cent of the acorns and that an additional 4.8 to 14.4 per cent was eaten in the trees.

TABLE 3. DAMAGE TO MATURE ACORNS.* BASED ON 14 RED OAKS AND 14 WHITE OAKS FOR A FIVE-YEAR PERIOD FROM FALL 1954 TO SPRING 1959

Acorn Condition	All Oaks	White Oaks	Red Oaks	Difference (White-Red Oaks)	Level of Significance** of Difference
	%	%	%	%	
Sound (undamaged)	13.5	11.6	14.6	-3.0	5%
Insect damage	32.8	29.1	34.8	-5.7	5%
Animal damage†	53.2	58.6	50.2	8.4	None
cut, on ground	30.0	25.5	32.5	-7.0	5%
missing from ground	5.5	7.0	4.6	2.4	None
missing from tree	17.7	26.1	13.1	13.0	None
Other	0.5	0.7	0.4	0.3	—
Total	100.0	100.0	100.0		

*Damage occurring within the period September to the following April.
**Determined from transformed data.
†Includes rodents, deer, and birds.

The relative amounts of damage by types for both red and white oak acorns are generally similar, although some real differences do exist (Table 3). Red oaks produced a significantly higher percentage of sound, undamaged acorns than white oaks. Of the total number of mature acorns produced, 14.6 per cent of the red oak acorns and 11.6 per cent of the white oak acorns were sound and undamaged. A regression analysis of the percentage of sound, undamaged acorns to the size of the mature acorn crop showed that the percentage of sound red oak acorns increased significantly with increase in size of the crop. For white oaks, the same trend occurred, although it was not significant. Damage to the acorns by insects and by animals cutting the acorns on the ground was also significantly greater for the red than for the white oaks.

The amount and types of acorn damages for trees exhibiting consistently high production were compared with trees having low production (Table 4). Three trees of each species with the highest production and three of each species with the lowest production were selected and studied. The two species were combined as the differences between types of damage for each species were similar and showed the same relative increase or decrease for each type of damage. In general, the relative amounts of damage by type between the six trees with high acorn production and the six with low acorn production were in close agreement, as indicated in Table 4. Again the damage by animals and insects was high, exceeding 80 per cent in each group. The high producers differed significantly from the low producers only in percentage of acorns missing

[Table 4. Acorn Damage of Oaks* With High Acorn Production and Low Acorn Production

Acorn Condition	Trees** with High Acorn Production	Trees† with Low Acorn Production	Difference (High-low Acorn Production)	Level of Significance of Difference‡
	%	%	%	
ound (undamaged)	8.5	5.8	2.7	None
nsect damage	38.5	24.9	13.6	None
ınimal damage	52.4	68.8	-16.4	None
cut, on ground	37.9	32.7	5.2	None
missing from tree	4.6	1.8	2.8	5%
missing from ground	9.9	34.3	-24.4	None
)ther	0.6	0.5	0.1	——
Total production	100.0	100.0		

*Red and white oaks combined.
**Red oaks number 3, 9, 17; white oaks number 1, 5, 18.
†Red oaks number 14, 16, 27; white oaks number 2, 13, 23.
‡Determined from transformed data.

rom the ground, with the high producers having a greater loss than the ow producers. This loss, however, represents only a small part of the otal damage.

An attempt was made to contrast amount of acorn damage by types or abundant seed years with poor seed years. However, the results were so erratic, especially for white oak, that little was learned.

Discussion

When a forestry program is developed in any locality, the forester must know the site requirements of the important tree species so he can favor those species which will grow well and produce the desired crops on each site. As the program progresses and management becomes more intensive, greater emphasis is placed on the production of superior individual trees.

The desirable characteristics of a superior tree depend somewhat on its intended use and may include such qualities as straightness of stem, rate of height growth, wood density, and uniformity or figuration of wood. When stands are regenerated by such natural methods as selection, shelterwood, or seed-tree, superior individuals could be maintained for the production of seed. When artificial regeneration is the principal consideration, a group of superior trees may be left as seed block, or the progeny of superior individuals may be raised in orchards for a source of high-quality seed. Nursery stock can then be produced from seed collected in the orchards, and planted as needed, or the seed may be sown directly on the ground, a method now being increasingly used.

When such superior individuals are selected, and the seed produced used either for natural or artificial regeneration, the quantity of seed produced by each selected tree becomes an important consideration, especially if great variation in size of seed crop exists among individuals of that species.

Results of this research on production of acorn crops suggest that inherent factors played a large role in determining the differences in crop size among individual oaks within each of the two species, northern red oak and white oak.

Within the same year, great variations were found in number of acorns produced among individual trees, even for individuals of the same species and size which were growing on similar, or even the same, sites. Good acorn producers tended to produce abundantly most years, with white oak being more consistent in this respect than red oak.

Natural regeneration methods are commonly used to reproduce oak stands, the reproduction being obtained partially or largely from the seed produced by trees left standing after the first cut. The amount of seed produced by these standing trees is particularly important when a heavy first cut is made, such as in the shelterwood method, and when reproduction established prior to the cut is scarce. The knowledge that oaks have such marked individual variation in size of seed crop may be used to advantage when marking mature trees. Individual oaks of high quality which are abundant seed producers should not be taken in the first cut if reproduction is scarce. They should be left for the purpose of regenerating the area.

Since the better acorn producers within a species tend to be consistently high producers relative to the average most years, unless a crop failure occurs, these individual trees should be spotted in advance and marked for holding beyond the first cut. Such a system would reserve a high percentage of the best acorn producers, and should be a factor in increasing the amount of reproduction, and perhaps in shortening the time required to obtain adequate stocking.

Summary

This bulletin presents the results of a study on production of northern red oak and white oak acorns, and the amount and types of acorn damage. The data were obtained from 14 red and 14 white oaks over a 5-year period. The major findings are as follows:

. Mature Acorn Production

The great variation in number of acorns among the individuals vithin the species and among years was outstanding. The red oaks produced a yearly average of 170 acorns per milacre of crown areas as ompared with 96 for the white oaks. The trees of both species with the ighest average production produced the largest crop per tree almost very year, whereas the poorest producers have small crops each year. This tendency was more pronounced in the white than in the red oaks. Variation in size of acorn crop was greater among trees than among ears. This difference was more pronounced in white oaks than in red.

2. Individual Tree Production by Sites

Size of the acorn crop showed no strong relationship to site quality, although the production by white oaks was relatively lower than the ed oaks on the better sites (site index 75 to 80). Far more pronounced han the effect of site on acorn production was the variation in production among trees of the same size on similar sites, the variation again being greater among the white than among the red oaks.

3. Immature Acorn Production

The number of immature acorns of both red and white oaks made up 34.7 per cent of the total crop. The number of immature acorns was positively related to the crop size, thus, as the total number of acorns ncreased, the number of immature acorns increased proportionally. A endency was noted for certain trees to be relatively high producers of mmature acorns. However, these trees were not among the highest crop producers.

4. Damage to Acorns

The acorn crops were heavily damaged by agents, especially animals and insects. The condition of all acorns follows: sound, 13.5 per cent; nsect damage, 32.8 per cent; animal damage, including cut on ground, missing from ground, and missing from tree, 53.2 per cent; and other, 0.5 per cent. In general, the relative amounts of damage by type are in close agreement between the two species, and between trees that are inherently high and low acorn producers.

5. Application of Crop Variation

The great variation in size of acorn crops produced among trees within a species has been discussed, especially from the standpoint of reproducing mature oak stands by natural regeneration methods.

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