Masting Characteristics of White Oaks: Implications for Management

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Abstract: Acorn production is variable from year to year and among species. Weather, insect damage, and genetics are primary causes for variation. Silvicultural techniques have been recommended to improve acorn production; however, those recommendations primarily address variation among red oaks (*Quercus rubra*). Variability among individual white oaks (*Quercus alba*) has not been well documented and is an important consideration for forest and wildlife managers. We measured acorn production among 200 white oaks on two sites—one in east Tennessee and one in western North Carolina, 2006–2008. Acorn production varied by site and year, and acorn yield was highly variable among individuals, as one-third of the trees produced approximately 75% of the acorns collected at both sites. Approximately one-half of the trees at both sites were poor producers and yielded only 10% of the acorns collected. Acorns per m^2 was not influenced by diameter at breast height, crown area, or production frequency of individual trees. Thus, with no accurate predictor of acorn yield, acorn production surveys during late summer should be conducted for no fewer than three years to identify good producers. We encourage managers to evaluate mast production of white oaks prior to deciding which trees to retain during two-aged regeneration harvests or timber stand improvement. Our data suggest net white oak acorn production can be maintained in a stand, and over time potentially increase, with removal of up to 50% of the white oaks.

Key words: white oak, *Quercus alba*, oak mast, acorns, southern Appalachian oaks

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Acorns are a primary source of nutrition for many wildlife species (Schroeder and Vangilder 1997). In some areas, acorn crops may influence the population density of several species, including white-tailed deer (*Odocoileus virginianus*; Wentworth et al. 1992), black bear (*Ursus americanus*; Eiler et al. 1989), ruffed grouse (*Bonasa umbellus*; Norman and Kirkpatrick 1984), and squirrels (*Sciurus* spp.; Nixon et al. 1975). Oaks also represent a significant hardwood forest resource and are characterized by high-quality timber production (Hicks et al. 2004). Thus, variability in acorn production is an important consideration for forest and wildlife managers throughout the eastern United States.

Genetics likely plays an important role in acorn production by individual trees (Greenberg and Parresol 2002). However, variation from year to year is largely a result of environmental factors (including poor pollination following continuous rain and/or insufficient wind, late frosts, and drought), basal area, and age (Sharp and Sprague 1967, Goodrum et al.1971, Sork et al. 1993, Healy 1997). Because environmental factors cannot be controlled, the inherent capability of individual trees to produce acorns should be of primary interest when considering forest management practices to perpetuate an oak-dominated stand and when managing stands for wildlife.

Silvicultural techniques can influence acorn yield. Acorn production among individual oaks may be negatively correlated with stand density (Healy 1997) and basal area (Perry et al. 2004). Thinning can increase mast production (Healy 1997, Guariguata and Saenz 2002, Perry and Thill 2003, Perry et al. 2004, Lombardo and McCarthy 2008) and increase production of sound acorns (Guariguata and Saenz 2002). Studies have suggested retention of good acorn producers in partial overstory harvests and thinning operations to maximize future masting potential (Harlow and Eikum 1963, Sharp and Sprague 1967, Goodrum et al. 1971, Healy 1997). However, previous work has primarily concentrated on red oaks (*Quercus* subgenus *Erythrobalanus*). Masting characteristics of individual white oaks (*Quercus alba*) are not well documented and there are no clear determinants of acorn production performance except that good producers for white oak have been characterized as trees in dominant and codominant crown positions (Downs and McQuilken 1944, Cypert 1951, Sharp 1958).

From 2006–2008, we collected pretreatment data for white oak acorn production prior to implementing thinning and fertilization treatments. Our goals were to identify inherently good and poor mast producers, and to determine if diameter at breast height or crown area influenced acorn density per m^2 crown area. We present these data to provide information related to acorn-producing characteristics of white oaks, which forest and wildlife managers should find useful when considering forest management practices in stands where white oak is an important component.

Study Area

We collected acorns from white oak trees at Chuck Swan State Forest and Wildlife Management Area (hereafter CS) in east Tennessee and at the Bent Creek Experimental Forest (hereafter BC) in western North Carolina. CS encompasses 9825 ha in the Ridge and Valley physiographic province of east Tennessee and is located about 60 km north of Knoxville. Elevation ranges from 310m to 520m. CS receives approximately 130 cm of rain annually. Common overstory trees include white oak, chestnut oak (*Quercus prinus*), northern red oak (*Quercus rubra*), black oak (*Quercus velutina*), hickory (*Carya* spp.), red maple (*Acer rubrum*), yellow poplar (*Liriodendron tulipifera*), blackgum (*Nyssa sylvatica*), and American beech (*Fagus grandifolia*).

BC encompasses 2500 ha within the Blue Ridge physiographic province of the Pisgah National Forest near Asheville, North Carolina. Elevation ranges from 700 m to 1070 m and annual precipitation averages 120cm. Common overstory tree species include scarlet oak (*Quercus coccinea*), chestnut oak, black oak, blackgum, sourwood (*Oxydendrum arboreum*), and occasional pines (*Pinus* spp.) on xeric sites. Yellow poplar and northern red oak are common on moist sites, and red maple, hickory, white oak, and flowering dogwood (*Cornus florida*) are common throughout the area.

Methods

We randomly selected 120 dominant or codominant white oaks within three mixed upland hardwood stands at CS and 80 dominant or codominant white oaks within eight mixed upland hardwood stands at BC. Each stand was located in a separate watershed. The soils in the stands selected at CS were in the Clarksville, Claiborne, and Fullerton series, which are historically associated with hardwood forests, well-drained, strongly acidic, gravelly or cherty, and normally found on side slopes, narrow ridgetops, and benches with an A-horizon 2–20 cm deep. The soils in the stands selected at BC included the French-Nikwasi, Saunook-Thurmont, Tuckasegee-Callasaja, Evard-Coweee, and Chestnut Buladean complexes. These soils are moderately to very deep, moderately well to well drained, and moderately to very strongly acidic (NRCS 2009).

We considered trees dominant or codominant if their crowns were at or above the general level of the canopy and received full light from above (Smith 1982). We avoided trees that overlapped with other white oak crowns to prevent overestimation of mast density (acorns/m^2 crown). We measured the diameter at breast height (DBH) of all trees in 2008. DBH ranged from 34–86 cm with a mean of 53 (SE = 0.8) cm at CS and 13–96 cm with a mean of 49 (SE = 2.5) cm at BC. We placed three 1-m^2 circular mesh baskets under the canopy of each tree and collected acorns every two weeks from early September–November 2006–2008. We discarded aborts and counted fully developed acorns in the lab. We calculated crown area by measuring radii in eight azimuths for all trees at CS in 2008.

We tested acorn viability in 2007 and 2008 at CS by float testing (Gribko and Jones 1995). We tallied floating acorns and sinking acorns and only considered sinking acorns sound.

When collecting acorns at CS in 2007 and 2008, we marked and returned up to 30 in the respective basket to monitor acorn depredation. We collected up to 50 sound acorns from each tree at CS in 2008, dried them to constant mass, and weighed them to the nearest 0.01 g to obtain mean acorn mass per tree.

Data Analysis

We compared the mean density of fully developed acorns per m^2 crown area to standardize measurements between trees. Because acorn soundness and depredation were not measured at BC, we used total acorn production (sound and unsound) for both sites and did not correct for acorn depredation in the analysis. We used a mixed model ANOVA ($\alpha = 0.05$) (SAS Institute 2004) to determine the year by site interaction. We corrected for non-normality with a square root transformation ($W = 0.66$). Non-transformed means are reported. We also used JMP 7 (SAS Institute 2007) to examine the correlation between DBH and acorns/m^2 crown area at both sites, and crown area and acorns/m^2 crown area at CS.

We categorized trees into production classes based on criteria modified from Healy et al. (1999), where good producers produced more acorns/m^2 crown than the five-year mean, moderate producers produced between the mean and 60% of the mean production, and poor producers produced less than 60% of the mean production. For our analysis, we used three years of data. In addition to Healy et al.'s (1999) definition of moderate and poor producers, we identified good producers as trees producing greater than the three-year mean but less than twice the three-year mean, and excellent producers as trees producing more than twice the three-year mean. We used mixed model ANOVAs ($\alpha = 0.05$; SAS Institute 2004) to examine differences in crown area (only at CS), DBH, and acorn mass (only at CS) among production classes. Ad-

Table 1. Annual mast crop characteristics of white oaks at the Bent Creek Experimental Forest (BC) and Chuck Swan State Forest (CS), 2006–2008

	2006		2007		2008	
	BC	CS	BC	CS	BC	CS
% trees producing	93	43	43	67	83	98
Acorns/m² crown (SE)[a]	42.5 (6.0) B	0.6 (0.2)C	1.1 (0.3) C	3.6 (1.0) C	27.1 (5.0) B	81.4 (9.0) A
Max. acorns/m² crown/tree	294	10	16	55	227	539
Min. acorns/m² crown/tree	0	0	0	0	0	0
% sound acorns				53		59
% acorns depredated				6		15

a. Different letters indicate differences in site*year ($F_{2, 390}=90.18$, $P<0.0001$).

ditionally, we calculated total acorn production/year using acorn density/m² crown area and measured crown area at CS, and used ANOVAs to examine differences in acorns/tree among production classes. We used a log transformation to correct for the non-normality (W=0.82) in crown area distribution. We report non-transformed means.

When ANOVAs were significant, we used Tukey's Honestly Significant Difference multiple comparison test to determine differences between means at $\alpha=0.05$ (SAS Institute 2004).

Results

Acorn production differed among years and sites (Table 1). At BC, the percentage of trees producing acorns and acorn yield was greatest during 2006 and 2008. At CS, the percentage of trees producing acorns and acorn yield was greatest in 2008, and slightly more than half of the acorns collected were sound. Acorn depredation from mast baskets at CS varied among years (Table 1).

There was no correlation ($P=0.08$) between acorn density per m² crown and crown area at CS. Acorn density per m² crown was positively correlated ($P=0.02$) with DBH at CS, but the relationship was unimportant as little variability in acorn production was explained ($R^2=0.05$). Similarly, acorn density per m² crown was correlated ($P=0.02$) with DBH at BC, but explained little of the variability ($R^2=0.06$).

Acorn production varied greatly by tree. Half of the trees at CS were designated poor producers (<60% of mean acorns/m² crown area) and they accounted for only 11% of the acorns collected (Table 2). Approximately one-third of the trees produced 74% of the acorns collected at CS. Likewise, at BC, excellent and good producers produced 78% of the acorns collected. Poor producers represented 44% of the trees at BC and produced only 6% of the acorns collected.

Additionally, there were no differences in DBH, crown area, or mean acorn mass among production classes (Table 3). Whereas means and standard errors of crown area suggest a difference between excellent and poor trees, the non-normality of crown area distribution and disparity in sample size ($n=16$ for excellent producers; $n=59$ for poor producers) prevent a statistical difference. Production classes did differ in total acorns/tree/year. The 16 excellent trees produced 2.7× as many acorns as poor trees from 2006–2008 (Table 3), and excellent trees produced 2.5× the acorn mass of the 59 poor trees in 2008.

At least half of the excellent producers yielded acorns two out

Table 2. Proportion of white oak trees and proportion of total acorns collected from trees by production class, Bent Creek Experimental Forest (BC) and Chuck Swan State Forest (CS), 2006–2008.

		Production class			
Site		Excellent	Good	Moderate	Poor
BC	% of trees	18	14	24	44
BC	Acorns/m² crown area	72.7	28.2	13.4	4.0
BC	% of acorns collected	54	24	16	6
CS	% of trees	13	18	19	50
CS	Acorns/m² crown area	94.5	44.3	22.3	6.6
CS	% of acorns collected	45	29	15	11

Table 3. Production class characteristics of 120 white oaks at Chuck Swan State Forest, 2006–2008.

	Production class			
	Excellent	Good	Moderate	Poor
n (% of trees)	16 (13)	22 (18)	23 (19)	59 (50)
DBH cm (SE)[a]	56.3 (2.7)	54.6 (1.4)	52.7 (1.9)	51.6 (1.1)
Crown area m² (SE)[b]	36.1 (6.4)	41.2 (4.7)	55.0 (13.0)	61.0 (7.1)
Total acorns/m² crown (SE)	94.5 (10.1)	44.3 (1.8)	22.3 (0.7)	6.6 (0.6)
Total acorns/tree[c] (SE)	3666 (765) A	1835 (243) AB	1171 (260) B	370 (55) C
% of total acorns produced	40	27	18	15
Sound acorn dry mass (SE)[d]	1.70 (0.10) g	1.74 (0.09) g	1.90 (0.11) g	1.93 (0.11)g
% sound 2007	33	48	58	54
% sound 2008	60	56	63	57
Mean acorns/m² crown 2006	1.5	1.2	0.2	0.4
Mean acorns/m² crown 2007	0.8	5.3	6.6	2.5
Mean acorns/m² crown 2008	281.3	126.3	60.2	17.1
Acorn biomass g/tree 2007[e]	17	184	402	160
Acorn biomass g/tree 2008[e]	10392	5043	3946	1138
% of acorn biomass 2007[e]	2	24	52	22
% of acorn biomass 2008[e]	51	25	19	15

a. DBH did not differ by production class ($F_{3, 116}=1.49$, $P=0.22$).
b. Crown area did not differ by production class ($F_{3, 116}=0.83$, $P=0.49$).
c. Letters indicate differences in acorns/tree among production classes ($F_{3, 116}=30.85$, $P\leq0.0001$).
d. Weight per acorn did not differ by production class ($F_{3, 102}=0.56$, $P=0.64$).
e. Only sound acorns (sinking) used to calculate biomass.

Table 4. Proportion of white oak trees producing acorns one, two, or three years at Chuck Swan State Forest and the Bent Creek Experimental Forest, 2006–2008.

	BC			CS		
Class	1 year	2 years	3 years	1 year	2 years	3 years
Excellent	0	64	36	31	50	19
Good	10	45	45	14	45	41
Moderate	0	85	15	26	57	17
Poor	20	57	23	28	25	47
All classes	8	64	28	22	48	30

of three years at both sites (Table 4). The majority of excellent and good producers yielded acorns at least two of three years. More moderate producers at BC yielded acorns in multiple years than at CS. Most of the trees at both sites, regardless of production class, produced acorns at least two out of three years. Approximately one-third of the trees at both sites produced acorns all three years, and one tree at each site failed to produce in any year.

Discussion

White oak acorn production differed among years and across sites and varied greatly from tree to tree. Although most of the trees at both sites produced acorns two out of three years, about one-half of the trees were poor producers. One-third of the trees produced approximately 75% of the acorns. Acorn viability at CS was comparable or better than what other studies have found with northern red, black, and chestnut oak (Bellocq et al. 2005, Lombardo and McCarthy 2008). Neither crown area nor DBH was a good predictor of acorn density per m² crown area, but while it is possible for poor producers with large crowns to produce more acorns than good or excellent producers with smaller crowns, it is unusual to find such disparity of crown area among dominant and codominant trees in the same stand. Our estimates of acorn production should be considered conservative because we collected acorns from open baskets. However, data collected at CS indicated acorn predation was low (Table 1.).

Our data suggest there are inherent limitations for acorn production among individual white oaks. This is consistent with previous work. Healy et al. (1999) reported only 39% of northern red oaks were reliable acorn producers, and Greenberg (2000) found that more than half of black, scarlet, chestnut, and white oaks were poor producers. Environmental factors certainly influence annual white oak mast production, but production *potential* is apparently governed by genetic traits among individual trees.

Several studies have correlated mast production to climatic variables, such as heavy precipitation or freezes during the late spring (Downs and McQuilken 1944, Harlow and Eikum 1963, Sharp and Sprague 1967, Goodrum et al. 1971, Sork et al. 1993). The mast failure we recorded in 2007 was the result of an unusually late freeze, 7–10 April (NOAA 2008c, NOAA 2008d). White oaks had already set flowers, and all young leaves were killed. Following the freeze, a record-setting drought resulted in a departure of –22 cm of precipitation from April through September at CS (NOAA 2008b), and –20 cm at BC (NOAA 2008a). We were unable to identify any potential environmental causes that could explain the mast failure at CS in 2006. Regardless of reason, the lack of acorn production at CS during 2006 and 2007 certainly led to the difference in regularity among production classes between sites. Our data clearly indicated more white oaks produced acorns, and more acorns were produced per m² crown area during good mast years than during poor mast years (Tables 1 and 4). Other studies have also reported a strong relationship between the number of trees producing acorns, acorn density on individual tree crowns, and acorn crop size (Greenberg and Parresol 2002, Greenberg and Warburton 2007).

We found no indicator for determining the acorn production potential of individual trees other than quantifying acorn production over several years. Healy et al. (1999) also found no criteria to predict good red oak acorn producers other than measuring yield for at least three years. Criteria used to determine excellent and good producers should be carefully considered because different strategies may result in the selection of different trees. For example, in our study, trees that produced acorns every year were not necessarily the best producers overall. Therefore, identifying trees that are producing acorns in a poor mast year will not accurately identify excellent or good acorn-producing trees. Like Healy et al. (1999), our data suggest acorn production of individual trees should be monitored for at least three years to identify excellent and good-producing white oaks. Monitoring acorn production of individual trees can be accomplished using visual surveys and acorn production indices to reduce the amount of time and effort required in identifying excellent- and good-producing trees (Whitehead 1969, Greenberg and Warburton 2007).

Although poor producers were more consistent producers at CS (Table 4), they were consistently poor producers. Removing some of these trees during forest management activities will enable trees remaining in the stand to grow larger crowns, expanding into space previously occupied by adjacent competitors, and ultimately produce more mast. Jackson et al. (2007) reported a 25% increase in white oak crown area just one year following competition removal. The increased sunlight entering the stand also increases available nutrition in the understory in the form of additional forage and soft mast (Jackson et al. 2007, Lashley 2009, and Jones et al. 2009). Even if a poor producer bears 2.5 acorns/m² crown/year (Table 1) in a poor year when other trees fail, those few acorns cannot sustain wildlife populations. This contention is supported by population declines and poor reproduction following poor mast years in vastly forested areas and has been documented for several wildlife species (Nixon et al. 1975, Norman and Kirkpatrick 1984, Eiler et al. 1989, and Wentworth et al. 1992).

Management Implications

Our data have implications for forest regeneration as well as habitat improvement for wildlife. Where a two-aged silvicultural system is desired, clearcutting with reserves or an irregular shelterwood are methods normally used in upland hardwood stands. During the forest management planning process, we recommend land managers identify as many moderate-to-excellent acorn producers as possible for retention. A random selection of oaks for retention, without regard for the acorn production potential of individual trees, may result in a missed opportunity for maximizing acorn production within harvested stands. In fact, there is a 50% chance a randomly-selected white oak tree will be a poor producer. We recognize identifying the better producers on large forested tracts is impractical. However, on smaller properties, and especially where acorn production for wildlife is an objective, it is entirely possible and prudent.

Ocular estimates with binoculars can be made in late August through early September, or observations on acorn drop can be made later in the season. Trees with consistent or relatively heavy yields may be marked with aluminum tags or flagging tape over several years. At this time, a better informed decision can be made for which trees to retain during two-aged regeneration harvests or during timber stand improvement (TSI) cuts or thinnings.

When implementing TSI for wildlife, such as retention cutting, most of the trees killed or removed are usually non-mast-bearing species (Jackson et al. 2007). However, depending on species composition, several mast-bearing species, including oaks, may need to be removed or killed in order to reduce canopy closure to the desired level. Although many wildlife managers may be reluctant to kill or cut oaks, our data suggest that up to 50% of the white oaks could be removed and still maintain the majority of acorn production if excellent, good, and moderate producers are identified and retained. We recommend forest managers retain a diversity of oak species, as well as other hard- and soft-mast producers, such as hickories, American beech, black cherry (*Prunus serotina*), persimmon (*Diospyros virginiana*), blackgum, and dogwood, when conducting two-aged harvests or TSI.

Care should be exercised when using mast surveys to predict stand-level acorn production. Surveys should include a large sample of trees to ensure trees in all production classes are evaluated. For example, the Whitehead visual survey (Whitehead 1969), a method commonly used by wildlife agencies, calls for sampling at least 25 individuals of each subgenus, while Greenberg and Warburton (2007) suggested up to 385 trees may be necessary to accurately assess acorn crops at a regional level using a similar visual survey. Additionally, managers should consider whether trees in geographically distinct areas (i.e., different watersheds, elevations, aspect, etc.) reflect the mast crop at a regional level or the crop at a few, isolated locations.

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