Analysis of Nine-Year-Old Sawtooth Oak Planted on Two Sites

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Abstract: Sawtooth oak (*Quercus acutissima*) seedlings of unknown provenance were planted on International Paper Company's Southlands Experiment Forest, Bainbridge, Georgia, on 2 sites, an old-field and a wild-land site. Treatments consisted of all oak, oak and loblolly pine (*Pinus taeda*), all pine, cultivation, and fertilization. After 9 years, pine was significantly larger ($P < 0.05$) than oak on both sites. On the old-field site neither cultivation nor fertilization showed a significant influence on the growth of either species. However, on the wild-land site cultivation significantly increased diameter, height, and volume of both oak and pine and survival of oak. Fertilization significantly increased diameter and volume of both oak and pine. Acorn production at age 9 appeared to be influenced only by spacing. Fertilization increased acorn crude fat and protein and decreased crude fiber.

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Industrial forest lands in the Southeast are managed primarily for pine production, resulting in the loss of most mast producing oaks. Oaks that remain are usually restricted to stream edges or other small sites not practical for intensive pine culture. This situation has led to a search for an oak as a mast source which would be available in the early stages of short rotations (30–35 years), and which grows rapidly enough to supply fiber within the limits of management for pines. Sawtooth oak holds promise as a "choice" wildlife food (Davison 1964) and fiber producer (Schoenike 1971).

Sawtooth oak is an oriental species that has attracted widespread attention because of its rapid growth and prolific mast production. Acorn production begins as early as age 5 (USDA 1970), compared to 20–25 years in native oaks (Collins 1961). Sawtooth oak acorn yields have been shown to be much greater than native oaks (Shaw 1971) and the acorns appear highly resistant to insect damage (Sullivan and Young 1961). Sawtooth oak acorns average 80–160/kg.

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Methods

Southlands Experiment Forest which is divided by the Flint River is a 6500-ha forest with diverse soil and vegetative conditions. The eastern half has predominantly clayey soils with loblolly pine. The western half, on which this study was installed, has mostly sandy soils supporting longleaf pine (*P. palustris*). Elevation ranges from 24 to 92 m above mean sea level. Average maximum temperature for the summer months is about 32 C. Annual rainfall is 126 cm, 56% of which occurs from March through August, the primary growing season.

Two study areas were selected which differed in land use history and soil type. Location 1 was an old-field site with soil in the Lucy series, a well drained, coarse, loamy sand. Soil at Location 2 was in the Orangeburg series, a well drained soil with a sandy loam surface and sandy clay subsoil. The latter site was clearcut, sheared, and windrowed, a process which pushed some of the thin layer of topsoil into windrows with the debris. Soil analyses before fertilization showed nutrient levels at both locations to be extremely low, especially at Location 2. Location 1 had 10 times more phosphorus (P) (18.5 vs. 1.8 kg/ha) and 2 times more potassium (K) (68 vs. 35 kg/ha) than Location 2. Magnesium (Mg), calcium (Ca), and pH levels were nearly the same in both locations. Both locations were pine sites and cannot be considered good for growing commercial hardwoods.

The study was installed during January and February 1973, using a split-plot design with 4 replications on each location. Each replication was split into cultivated, both between and across rows as needed to control competing vegetation during the first 3 growing seasons, and noncultivated plots. Sawtooth oak, loblolly pine and an oak-pine mixture were each hand planted in 49-tree-plots at 2.44 × 2.44-m spacing. In mixed plots, 4 rows of pine alternated with 3 rows of oaks. Fertilizer was applied 1 year after planting (April 1974) and consisted of (1) no fertilizer and (2) 5–10–15 Nitrogen (N)–P–K applied at a rate of 224 kg/ha.

In March 1979, pines were removed from the mixed plots, leaving 3 rows of oaks on a 2.44 × 4.88-m spacing. Based on soil analyses, fertilizers were again applied in the following rates: ammonium nitrate (34–0–0), 336 kg/ha; diammonium phosphate (18–46–0), 224 kg/ha; potash (0–0–46), 224 kg/ha; and dolomite lime, 1121 kg/ha.

At age 9 (February 1982) 25 trees in each of the 49-tree-plots were measured for height (H) and diameter at 1.4 m above ground (DBH). A volume index was calculated as $DBH^2 \times H$. Because the pines had been removed, only 15 trees were measured in the mixed species plots. In addition, replication 3 at Location 1 was deleted from this overall analysis because it was accidentally burned in March 1979. Many pines were killed but most oaks coppiced vigorously. Sprouts were measured but were not included in the basic analysis. All traits were analyzed using Analysis of Variance (ANOVA) procedures and each location was analyzed separately due to the magnitude of the site differences between locations. After each location was analyzed for species differences, each species-location group was analyzed for effects of cultivation and fertilization. All comparisons of means were conducted using Duncan's Multiple Range Test at a probability level of 0.05.

Acorn Production and Chemical Analysis

Acorn production was estimated at Location 1 (Reps 1, 2, 4) from randomly selected trees on each plot. Acorn counts were made on the first 2 trees encountered bearing acorns. Comparisons of means were made using Tukey's test at a 0.10 probability level.

Acorns were collected from fertilized and unfertilized trees for proximate chemical analysis. The pericarp was removed and the embryos were dried, ground and then analyzed according to standard AOAC procedures (Horwitz 1980).

Results and Discussion

Growth of sawtooth oak differed drastically between Location 1 (old-field site) and Location 2 (wild-land site) while pine growth changed slightly (Table 1). Oak survival differed 14.3% between locations from 98.0% (old-field) to 83.7% (wild-land). When competition overstopped sawtooth oak seedlings, they tended to die-back and then resprout on an annual basis. Stransky (1981) also described sawtooth oak as a species that does not compete well with other hardwoods.

Sawtooth oak compared well though significantly different from pine in height on the old-field site but pine grew twice as much in diameter and showed a 4-fold advantage in volume production (Table 1). At the wild-land site, pine showed greater superiority in growth over the oak. This difference between sites indicates that site selection as well as competition control

Table 1. Mean Values for All Traits at Age 9 for Sawtooth Oak and Loblolly Pine at Bainbridge, Ga.

	DBH (cm)	Height (m)	Vol. Index (D^2H)	Survival (%)
Location 1				
Oak (2.44 × 2.44 m)	7.55C[a]	7.80B	473.0C	98.0A
Oak (2.44 × 4.88 m)	9.21B	7.84B	716.0B	97.2A
Pine (2.44 × 2.44 m)	14.55A	8.56A	1,816.0A	87.3B
Location 2				
Oak (2.44 × 2.44 m)	2.08B	2.66C	32.8B	83.7B
Oak (2.44 × 4.88 m)	2.53B	3.08B	55.9B	85.4AB
Pine (2.44 × 2.44 m)	12.60A	8.35A	1,354.0A	90.5A

[a] Means not followed by the same letter are significantly different ($\alpha = 0.05$).

is much more critical to sawtooth oak than loblolly pine. On the old-field where hardwood competition was absent, oak had a significantly higher survival percentage than pine.

The mean diameter of sawtooth oak at the wider spacing was significantly greater than the narrow-spaced sawtooth oak at Location 1 but not at Location 2. However, height of wide-spaced sawtooth oak was significantly greater at Location 1 but when the 2-fold difference in stocking was considered, oak at the wider spacing had the least volume per hectare.

An ANOVA of sawtooth oak data alone indicated significant effects due to cultivation and fertilization. At Location 1 where competition for nutrients, light, and moisture was not severe, cultivation and fertilization had no significant effect (Table 2). The wild-land site data were entirely different from the old-field site. Cultivation significantly increased diameter, height, volume, and survival of sawtooth oak. Fertilization, however, had a significant effect only on diameter growth and resulting volume index. An increased nutrient supply improved the lateral growth of oak trees, but not height or survival, both of which are influenced by competition control (cultivation). The cultivation × fertilization interactions were all non-significant, indicating the effects were additive.

Loblolly pine showed similar trends as sawtooth oak. No significant differences in pine growth were detected on the old-field site (Table 2). At the wild-land site, cultivation significantly increased all types of growth but sur-

Table 2. Effect of Cultivation and Fertilization on the Growth and Survival (Means) of Sawtooth Oak and Loblolly Pine Saplings at Age 9 Planted on 2 Sites at Bainbridge, Ga.

	DBH (cm)		Height (m)		Vol. Index (D^2H)		Survival (%)	
	Oak	Pine	Oak	Pine	Oak	Pine	Oak	Pine
Location 1								
Cultivated	8.27A[a]	14.65A	8.47A	8.81A	594A	1,984A	99.3A	89.3A
Not Cultivated	6.83A	14.46A	7.13A	8.32A	353A	1,740A	96.7A	85.3A
Fertilized	8.03A	14.69A	8.19A	8.37A	541A	1,811A	98.0A	86.7A
Not Fertilized	7.07A	14.42A	7.41A	8.76A	406A	1,823A	98.0A	88.0A
Location 2								
Cultivated	3.26A	13.14A	3.53A	8.79A	59.6A	1,545A	91.5A	89.5A
Not Cultivated	0.90B	12.05B	1.79B	7.91B	6.0B	1,164B	76.0B	91.5A
Fertilized	2.97A	13.14A	3.41A	8.66A	57.4A	1,516A	84.0A	91.0A
Not Fertilized	1.20B	12.05B	1.89A	8.04A	8.3B	1,192B	83.5A	90.0A

[a] Comparisons were made within species and means not followed by the same letter were significantly different ($a = 0.05$).

vival was not affected. Fertilization-only increased the diameter, paralleling the results with the sawtooth oak data. The fertilization × cultivation interaction was non-significant; therefore, the effects were additive as with oak.

Shortly after the fire in March 1979, the oak sprouted and grew rapidly. Some flowering was observed during late spring of that year. In late winter 1980, the dominant sprout of each rootstock was selected and all others were cut. The few sprouts which had produced flowers in 1979 produced acorns in 1980. After 3 years growth, the sprouts had grown to within 20%–40% of the 9-year-old trees (Table 3).

Acorn numbers per tree varied widely, with the greatest plot average exceeding 700 acorns per tree (Table 4). Within a given tree spacing, there

Table 3. Means for Sawtooth Oak Sprouts 3 Growing Seasons Following a Fire at Bainbridge, Ga.

Treatment	No. Trees Killed Per Plot	DBH (cm) Unburned Plots	DBH (cm) Burned Plots	Height (m) Unburned Plots	Height (m) Burned Plots	Survival (%) Unburned Plots	Survival (%) Burned Plots
Cultivated & Fertilized	3	8.48	8.05	8.63	7.87	100.0	100.0
Cultivated Only	20	8.05	7.52	8.32	7.57	98.7	92.0
Fertilized Only	All	7.59	4.60	7.74	4.75	96.0	100.0
Control	All	6.07	5.30	6.52	5.25	97.3	100.0

Table 4. Sawtooth Oak Acorn Yield (Mean Number of Acorns Per Sample Tree) at Age 9 by Treatment and Tree Spacing on an Old-Field Site at Bainbridge, Ga.

	Spacing					
	2.44 × 2.44 m			2.44 × 4.88 m		
Treatment	Rep 1	Rep 2	Rep 4	Rep 1	Rep 2	Rep 4
Cultivate and Fertilize	81	105	216	227	702	176
Cultivate Only	111	25	16	368	177	532
Fertilize Only	73	106	548	676	217	408
Control	21	90	50	145	90	50

were no significant treatment effects which may be due to insufficient sample size since in the 25 trees/plot strata, the fertilized-twice trees yielded significantly more acorns ($P < 0.10$) than the more closely-spaced trees. It appears that room to grow has more influence on acorn production than tree nutrition. This cannot be stated confidently because these differences may be due to the larger tree sizes with more limbs to bear acorns.

Sawtooth oak is taxonomically a white oak. Acorns in this group are higher in crude protein and ash, much higher in nitrogen-free extract (NFE), and much lower in fat and fiber than black oak acorns.

Sawtooth oak acorn embryos compared to native white oaks were similar in crude protein and ash, above average in NFE, and below average in fiber and crude fat (Table 5). This same relative composition was apparent in analyses of whole acorns (Short 1976).

Fertilization with N and P significantly increased crude fat and protein and decreased crude fiber (indigestible carbohydrates), while total ash (minerals) remained unchanged. This resulted in a slight decrease in NFE (a measure of digestible carbohydrates) which is calculated by subtracting from 100 the sum of the 4 aforementioned components. Composition of Ca, K, and Mg did not change significantly but P decreased significantly and manganese (Mn) increased significantly in acorn embryos from fertilized trees. These changes may be related in part to the tree's allocation of nutrients in the parts of the acorn. For example, the "husk" or pericarp contains the bulk of the acorn's ash (minerals) (Mawk 1976) and more of the available P and less of the Mn may have been concentrated in the pericarp. It is also possible that more rapid tree growth with fertilization caused certain nutrients to be used for wood and foliage production rather than for fruit development.

It is not known whether the slight (but statistically significant) differences in composition would be nutritionally important in the diet of wild animals. Fertilized sawtooth oak acorns should be more digestible because they contain less fiber and more energy-providing components (NFE, fat, and pro-

Table 5. Chemical Components of Sawtooth Oak Acorns by Fertilizer Treatment Compared to Acorns of Oaks Native to the Southeast

	Mean Percent By Dry Weight (acorn embryo)			
	Sawtooth Oak[a]		Native Oak Groups[b]	
Chemical Component	Fertilized	Unfertilized	White	Black
Crude fat	3.825***[c]	3.225	7.77	6.31
Crude protein	7.261**	6.491	5.43	23.30
Crude fiber	1.575*	2.065	5.74	16.64
N-free extract	85.014*	85.887	78.40	53.00
Ash	2.325NS	2.332	2.68	1.77
Ca	0.036NS	0.038		
P	0.087***	0.098		
K	0.605NS	0.592		
Mg	0.054NS	0.054		
Mn	0.005***	0.007		

[a] Data from collections made at Bainbridge, Ga.
[b] Data on 5 white oak and 4 black oak group species (after Mawk 1976) calculated to moisture-free percentages.
[c] Means significantly different at P of 0.01 (***), 0.02 (**), 0.10 (*) or NS (not significantly different, $P > 0.2$).

tein). This may be important since acorns are valuable as a wildlife food because they supply energy (Short 1976).

Management Considerations and Conclusions

The use of exotic species as a substitute for a native species or to fill an unoccupied niche is common in American wildlife management history. In many cases, this practice has met with disastrous results. Coblentz (1981) addressed the dangers of exotic introduction and questioned the use of sawtooth oak. Hopkins and Huntley (1979) emphasized that native mast producers, where they can be managed, should not be replaced with sawtooth oak. Both are valid concerns; however, since nearly 200 bird and animal species eat acorns (Martin et al. 1951), many wildlife biologists believe that additional losses of mast bearing hardwoods should be detrimental to wildlife. On industrial forest land, oaks are removed when mixed pine-hardwood stands are converted to pine plantations. Plantation rotation lengths are rarely long enough for native oaks to reach mast bearing age. Although groups of mature native oaks should be retained within or adjacent to pine plantations (Buckner and Landers 1980), plantings of sawtooth oak are an alternative for supplying mast. Besides its early and prolific acorn production, sawtooth oak can provide a source of oak fiber for papermaking on intermediate and better pine sites. For these reasons, research within International

Paper has been expanded into genetic and seed source selection and identification of favorable site factors.

Sawtooth oak can be grown on a variety of sites (Sullivan 1974) but is intolerant of vegetative competition. Thorough site preparation and competition control, e.g., disk cultivation, common practices for hardwood plantations (Hunt 1975), are necessary for successful stand establishment. Tree spacing was very important to acorn production, perhaps even more important than soil nutrition. Individual tree volume was also greatest in wider spaced trees. However, we recommend planting enough seedlings to allow selective thinning of a stand after initial growth and acorn production can be evaluated (about age 5–7). Plantings should be grouped and situated near other forest stands that are acceptable habitat for the targeted wildlife species. Single row interplantings of sawtooth oak should be avoided due to shading from faster growing pines and the cost of intensive culture on single rows.

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