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Growth expectations from alternative thinning regimes and prescribed burning in naturally regenerated loblolly-shortleaf pine stands through age 20

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Abstract

Pine growth was monitored for 14 years after mechanically strip-thinning a dense, naturally regenerated, even-aged stand of 6-year-old loblolly pines (*Pinus taeda* L.) and shortleaf pines (*Pinus echinatu* Mill.) that averaged 41 000 trees per hectare in southeastern Arkansas, USA. Prescribed winter bums were conducted biennially between ages 9 and 20 years. A commercial thinning during the 17th growing season left a residual stocking of either 19.5 m^2 ha^{-1} or 494 crop trees ha^{-1} in merchantable-sized (> 9.0 cm dbh) pines on plots that were precommercially thinned and on plots that were not. Precommercial thinning enhanced pine growth in total height and in diameter at breast height (dbh, taken at 1.37 m) through stand age 20 years. At age 20, present net value (PNV) averaged highest on plots that were precommercially thinned at age 6 then commercially thinned to 494 crop trees per hectare after 16 years because of increased production in sawtimber (trees over 24 cm dbh). The second highest PNV at age 20 was on unmanaged control plots because no costs were incurred for precommercial thinning, hardwood injection, prescribed burning, or timber sale administration. Within each thinning treatment, pine dbh growth decreased in the 18th and 20th year relative to an increase in the degree of crown scorch from prescribed winter bums that were conducted after 17 and 19 years, respectively.

Keywords: **Crown scorch; Growth;** Yield; Thinning; *Pinus echinatu* Mill.; *Pinus taeda* L.

1. Introduction

Natural regeneration of loblolly (*Pinus taeda* L.) and shortleaf pines (***Pinus echinatu*** Mill.) is considered successful on cutover sites when seedling densities average over **3700** stems ha^{-1} the first year after establishment or over 1700 stems ha^{-1} by the third growing season (Grano, 1967). Quadrat stocking of these natural seedlings should range from 40% (Campbell and Mann, 1973) to 60% (Trousdell, 1963).

An often-cited disadvantage for natural regeneration of southern pines is the inability to control density at the time of establishment (Bamett and Baker, 1991). Loblolly pines, for example, tend to produce good seedcrops during 3 out of 5 years (Cain, 1991) or 7 out of 10 years (Cain, 1993a) in the Upper Coastal Plain of the West Gulf Region, southeastern USA. When these seeds are disseminated onto receptive sites during above-average seedyears, excessive pine density is usually the rule rather than the exception.

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To shorten the rotation of crop trees in overly dense, natural stands and to reduce the risk of loss by fire, insects, diseases, and weather, precommercial thinning of loblolly and shortleaf pines is recommended. Generally, that recommendation applies only to stands where density exceeds 12300 stems ha^{-1} or where live-crown ratio of the dominant pines is expected to be less than 35% at the time of the first commercial thinning (Mann and Lohrey, 1974). When assessing the need for precommercial thinning in dense natural pine stands, the number of dominant and codominant pines is a more important criterion than total density (Cain, 1993b). To maximize early volume production in loblolly pines, a density of no more than 1850 trees ha-' has been reported as optimum (Lohrey, 1977).

When a landowner's objective is sawlog (> 24 cm diameter at breast height (dbh)) production, then precommercial thinning of dense natural pine regeneration has more merit than if a pulpwood (9.1-24 cm dbh) rotation is planned. Concomitantly, a variety of commercial thinning regimes can be adopted to enhance early sawlog production in even-aged natural stands. To that end, the objective of this study is to evaluate four thinning treatments and an unmanaged control relative to the growth of naturally regenerated loblolly and shortleaf pines. Precommercial thinning was evaluated from age 6 through 16 years, after which pines were commercially thinned (Cain, 1993b). Results through age 20 are reported here. The consequences of biennial, prescribed winter burning on pine growth and non-pine vegetation were also investigated.

2. Material and methods

2.1. *Study area*

The study is located on the Upper Coastal Plain in southeastern Arkansas, USA, at 33°02′N mean latitude and 91°56′W mean longitude. Elevation is about 40 m with a gradual slope of 3% from north to south. Soils are Providence and Bude silt loams-Typic and Glossaquic Fragiudalfs, respectively-that are moderately well drained (USDA, 1979). Site index is 26 m at 50 years for loblolly and shortleaf pines.

Within a mature pine stand, a 4.05-ha strip (100.6 m east-west by 402.3 m north-south) was clearcut and rootraked in 197 1. Residual slash was piled and burned for the establishment of a research planting area. The area was maintained for planting by periodic mowing through 1973, but planting was never done. Between 1972 and 1974, the clearcut naturally regenerated because it was bounded on the west by a mature stand of loblolly and shortleaf pines. The area remained undisturbed until 1979 when an inventory revealed an average of 41000 pines ha^{-1} in seedling ($\leq$ 1.40 cm dbh) and sapling (1.40 cm $<$ dbh $\leq$ 9.0 cm) size classes. Although natural seeding may have occurred over a period of 2-3 years until the receptive seedbed disappeared, a count of annual growth rings at groundline indicated that the pines were 6 years old in the autumn of 1979, when species composition was 70% loblolly and 30% shortleaf pines.

2.2. *Cultural treatments*

2.2.1. *Precommercial thinning*

In October 1979, 12 0.16-ha plots were established within the 4.05 ha clearcut on areas with the most uniform pine density and quadrat stocking. Plots measured either 40.2 $\times$ 40.2 m^2 or 37.2 X 43.6 m^2 and were located throughout the 4.05-ha strip. Six plots were randomly selected for precommercial thinning and the other six were retained as unthinned controls. Thinning was accomplished with a heavy-duty rotary mower attached to an industrial-sized wheeled tractor. Plots were strip-thinned by mowing 3.66-m-wide swaths that alternated with 0.3-m-wide uncut strips. Mowing was facilitated by the intensive site preparation that was employed 8 years earlier because there were no stumps or other obstructions on the area. A time study indicated that pines on the entire 4.05-ha strip could have been precommercially thinned by this technique for less than $62 ha-‘, which was comparable with mechanical precommercial thinning costs ($82 ha^{-1}) reported across the southern US in 1979 (Belli et al., 1993).

2.2.2. *Prescribed burning*

In January 1983, when the pines were 9 years old, a biennial prescribed burning program was initiated on all 12 plots for fuel hazard reduction and for control of non-pine vegetation. Three additional 0.16-ha plots were established in residual unthinned areas before burning and were retained as unmanaged controls (no precommercial thinning and no burning). Plot dimensions for these unmanaged controls were the same as for the original 12 plots. Prescribed bums were repeated as follows: February 1985, March 1989, February 1991, and February 1993. The six unthinned plots, out of the original 12, were also prescribe burned in March 1987, but burning was deferred on the six precommercially thinned plots that year because the two earlier bums resulted in undesirable crown scorch.

2.2.3. *Commercial thinning*

Pines on each of the 12 original 0.16-ha plots were commercially thinned during the 17th growing season (1990), in accordance with plantation thinning regimes adapted from Zahner and Whitmore (1960) as outlined below.

Conventional thinning: merchantable-sized pines ($>$ 9.0 cm dbh) were thinned from below to a residual basal area (BA) of 19.5 $m^2 ha^{-1}$ (mean density 1700-1900 trees ha^{-1}). There are three replications on no-prethin/ bum plots (NPT/19.5BA) and three replications on prethin/ bum plots (PT/19.5BA).

Four hundred and ninety-four crop trees ha-' : all merchantable-sized pines were harvested with the exception of 494 crop trees ha^{-1} (mean BA 14-15 m^2 ha-'). There are three replications on no-prethin/bum plots (NPT/494CT) and three replications on prethin/burn plots (PT/494CT).

Unmanaged control: there are three replications with no thinning and no prescribed burning (UMC).

Commercial thinning was accomplished by a contract vendor using three two-man crews and one rubber-tired tractor with a self-contained grapple and pallet to forward 1.2-m lengths of pulpwood ricks to a loading point. One man on each crew operated a chain saw and the other man hand-stacked the pulpwood bolts for grapple loading onto the forwarder.

Following commercial thinning, density of residual submerchantable-sized pines ($\leq$ 9.0 cm dbh) was equalized across all commercially thinned plots by chain-saw felling to leave 2.3 m^2 of basal area ha-'. In the spring of 1991, residual hardwoods ($>$ 1.40 cm dbh) on thinned plots were controlled by stem injection of glyphosate (*N*-[phosphonomethyl] glycine) herbicide [1] (50% dilution with water); hardwoods on unmanaged control plots were left untreated. By applying one incision per 2.5 cm of dbh with 1 ml of herbicide solution per incision and using a mean dbh of 7.6 cm, the cost of herbicide injection in 1991 was determined to be \$19.77 ha^{-1} on precommercially thinned plots (297 stems ha-') and \$49.42 ha^{-1} on plots that were not precommercially thinned (741 stems ha^{-1}).

2.3. *Measurements*

During the course of each prescribed bum, from 80 to 100 ocular estimates of flame length were recorded by treatment. These estimates were used to calculate fireline intensity according to Byram (1959). Weather and fuel conditions were recorded at the time of each bum, but only results from the two most recent bums are reported here.

When pines were 12 years old, 40 dominant and/or codominant pines per interior 0.08-ha plot (494 trees ha^{-1}) were selected as future crop trees on all 15 plots and were tagged for identification. Crop trees were selected on the basis of crown class, tree quality, and spacing. More loblolly pines (94%) than shortleaf pines (6%) were chosen as crop trees because fewer shortleaf had achieved dominant or codominant crown status by age 12. From age 12 to 16 years, total height (to 3.0 cm) and dbh (to 0.3 cm) measurements were taken biennially on the 40 crop pines per plot. At stand ages 18 and 20 years, dbh measurements (to 0.3 cm) were taken on all 494 crop pines ha^{-1}. At 18 years, a 25% sample of these crop pines was selected on each plot for measurement of total height (to 3.0 cm), height to live crown (to 3.0 cm), and crown width at the widest axis and perpendicular to that axis (to 3.0 cm>. These same sample trees were utilized at 20 years for height and crown measurements. Selection criteria for these sample pines were as follows. (1) An equal number of sample trees was chosen from each dbh class per plot. (2) The number of sample trees was proportional to the species represented (loblolly or short-

[1] Discussion of pesticides in this paper is not a recommendation of their use and does not imply that uses discussed here arc registered by appropriate State and/or Federal agencies.

leaf) on any one plot. (3) Sample trees were free from obvious defects (i.e. bole fusiform, forked mainstem, broken tops, bark beetle infestations, or logging damage).

Following commercial thinning, residual non-crop pines and hardwoods that were over 1.40 cm dbh were inventoried biennially on each of the 15 plots by 2.5cm dbh classes. Inventories on interior 0.08-ha subplots were kept separate from the 0.08-ha isolations.

Within 4 weeks after prescribed winter bums at stand ages 17 and 19 years, percent of foliar scorch (i.e. crown scorch) was ocularly estimated on all 494 crop pines ha^{-1} by two individuals standing at different angles from each tree. Crown scorch is defined as the browning of needles in the crown of a tree and is caused by heat from a fire (McPherson et al., 1990). Scorch estimates were made to the nearest 10% between the values of 10% and 90%. Below 10% and above 90%, crown scorch was assessed to the nearest 2%. At the same time, dbhs were measured to 0.3 cm on each tree.

Volumes for crop pines were computed in accordance with Farrar and Murphy (1988). Volumes for all residual merchantable-sized pines were computed from the number of trees by dbh class according to a local volume table (Reynolds, 1959). In the local volume table, pulpwood volumes were to an 8.9-cm top, and sawlog volumes were to a 19. l-cm top, inside bark. On a plot-by-plot basis, volume production was calculated from pines marked to cut after 16 years plus volume in residual pines at 20 years.

In autumn 1993, at stand age 20, five 4-m' circular quadrats were systematically established within each of the 15 interior subplots for assessing percent ground coverage from non-pine vegetation. These assessments were made by the same individual on all plots. Percent ground coverage was ocularly estimated to the nearest 10% between the values of 10% and 90%. Below 10% and above 90%, ground coverage was assessed to the nearest 2%. Non-pine ground cover included that from hardwoods, shrubs, and herbaceous vegetation (i.e. graminoids, forbs, semi-woody plants, and vines).

2.4. *Data analysis*

The experimental design was completely randomized. Analysis of covariance was used to compare mean dbh, total height and volume per tree among the four commercial thinning treatments and the unmanaged control. For analysis of 20-year means, covariates were initial dbh, total height, and volume of crop pines at the time of their selection (age 12). For analysis of annual crop pine growth from age 16 through 20 years, covariates were dbh, total height, and volume of crop pines at the time of commercial thinning (1990). Analysis of variance was used to compare mean crown widths and live-crown ratios among treatments, as well as basal area and percent ground coverage at 20 years. Percent data for live-crown ratio and ground coverage were analyzed following arc sine transformation. Statistically significant differences ($\alpha < 0.05$) in treatment means were isolated by orthogonal contrasts: (1) UMC versus NPT/19.5BA + PT/19.5BA + NPT/494CT + PT/494CT; (2) NPT/19.5BA + PT/19.5BA versus NPT/494CT + PT/494CT; (3) NPT/19.5BA versus PT/19.5BA; (4) NPT/494CT versus PT/494CT.

Linear regressions were generated using crop pines to illustrate dbh growth trends during the 18th and 20th year, relative to crown scorch from prescribed burning at stand ages 17 and 19 years, respectively. Regression analyses were conducted on ocular estimates of percent crown scorch after arc sine transformation using radians.

An estimate of present net value (PNV) was based on the following assumptions. The cost of precommercial thinning in 1979 was \$82 ha^{-1}(Belli et al., 1993). Prescribed burning costs were also derived from Belli et al. (1993), by year of treatment and ranged from \$10.18 ha-' in 1982 to \$27.06 ha^{-1} in 1992. Costs for timber cruising and marking of trees for commercial harvest in 1989 were \$25.92 ha^{-1} (Belli et al., 1993). Hardwood control cost was based on stem density and the retail price of herbicide (\$29 l^{-1}) at the time of treatment in 1991. These costs were compounded through age 20 because income from the first commercial thinning was not high enough to retire all costs. Interest rates of 4%, 7%, and 10% were used to reflect low, medium, and high values.

Thinning from below to a residual basal area of 19.5 $m^2 ha^{-1}$ on unmanaged control plots after 16 years would have removed 31.9 m^3 ha-‘, which was valued as an opportunity cost and was compounded

Table 1
Mean size of crop pines in naturally regenerated loblolly-shortleaf pine stands at age 20

Thinning treatment and orthogonal contrast	dbh (cm)	Height (m)	Volume (m^3 per tree)	Crown width (m)	Live-crown ratio (%)
Mean tree size					
(1) Unmanaged control	18.8	16.1	0.182	4.0	38.6
(2) No prethin, commercial thin to 19.5 $m^2 ha^{-1}$ after 16 years	19.0	15.5	0.177	4.5	39.9
(3) Prethin at 6 years, commercial thin to 19.5 $m^2 ha^{-1}$ after 16 years	21.7	17.7	0.260	5.2	50.0
(4) No prethin, commercial thin to 494 crop trees ha^{-1} after 16 years	19.8	15.4	0.194	5.1	43.4
(5) Prethin at 6 years, commercial thin to 494 crop trees ha^{-1} after 16 years	22.6	17.4	0.272	5.6	54.5
Mean square error	0.0644	0.1674	0.0003	0.1176	0.0003
$P > F$ [a]	0.0001	0.0118	0.0010	0.0015	0.0001
Treatment contrast	Probability of a greater F [a]				
(1) vs. (2) + (3) + (4) + (5)	0.0001	0.1829	0.0037	0.0007	0.0001
(2) + (3) vs. (4) + (5)	0.0004	0.3888	0.1717	0.0240	0.0017
(2) vs. (3)	0.0001	0.0001	0.0002	0.0301	0.0001
(4) vs. (5)	0.000 1	0.0002	0.0004	0.0799	0.0001

[a] The probability of obtaining a larger F-ratio under the null hypothesis.

Table 2
Mean annual growth of crop pines in naturally regenerated loblolly-shortleaf pine stands during 4 years after commercial thinning

Thinning treatment and orthogonal contrast	dbh (cm)	Height (m)	Volume (m^3/tree)
Annual growth			
(1) Unmanaged control	0.62	0.72	0.0193
(2) No prethin, commercial thin to 19.5 $m^2 ha^{-1}$ after 16 years	0.67	0.63	0.0190
(3) Prethin at 6 years, commercial thin to 19.5 $m^2 ha^{-1}$ after 16 years	0.88	0.88	0.0285
(4) No prethin, commercial thin to 494 crop trees ha^{-1} after 16 years	0.88	0.55	0.0227
(5) Prethin at 6 years, commercial thin to 494 crop trees ha^{-1} after 16 years	1.05	0.8 1	0.0295
Mean square error	0.00159	0.0022	4.16×10^{-6}
$P > F$ [a]	0.0001	0.0006	0.0003
Treatment contrast	Probability of a greater F [a]		
(1) vs. (2) + (3) + (4) + (5)	0.0001	0.8594	0.0021
(2) + (3) vs. (4) + (5)	0.0001	0.0302	0.0737
(2) vs. (3)	0.0001	0.0001	0.0003
(4) vs. (5)	0.0004	0.0001	0.0028

[a] The probability of obtaining a huger F-ratio under the null hypothesis.

from age 16 to 20 years. Cost of site preparation in 1971 was not included in the PNV analyses because it was the same for all plots.

Product values in southern Arkansas in 1989 (stand age 16) and 1993 (stand age 20) were obtained from the *Forest Marketing Bulletin* published by the Arkansas Cooperative Extension Service, Little Rock, AR. Third-quarter (July-September) stumpage prices for pine pulpwood were \$6.36 m^{-3} in 1989 and \$9.90 m^{-3} in 1993 (based on \$ per cord). Also in the third quarter of 1993, pine sawlog stumpage prices averaged \$41.34 m^{-3} (based on International 0.25inch log rule).

3. Results

3.1. Crop pine response to thinning treatments

At age *20,* crop pines on precommercially thinned plots averaged more than 2.5 cm larger (P = 0.0001) in dbh than crop pines on plots that were commercially thinned without prethinning (Table 1). Crop pines across all thinned plots averaged 10% larger (P = 0.0001) in dbh at 20 years compared with those on unmanaged control plots. For annual dbh growth from age 16 to 20 years, crop pines that were commercially thinned to 494 crop trees ha-' outper-

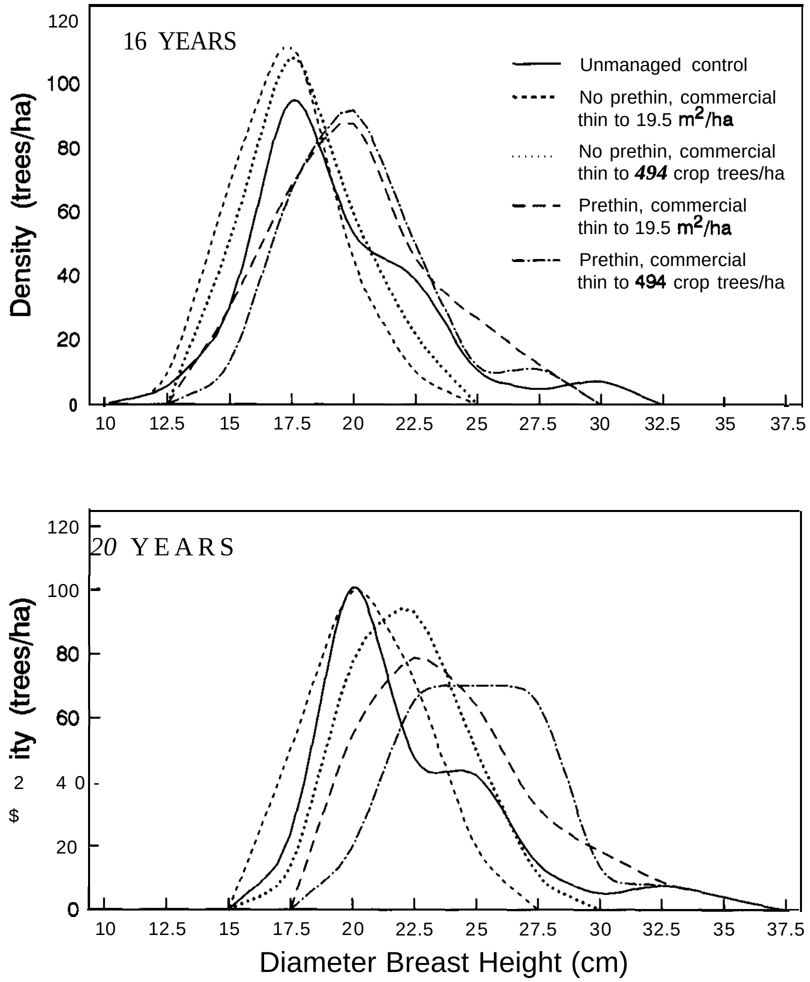

Fig. 1. Number of trees by *2.5-cm* dbh classes for the 247 largest crop pines per hectare at ages 16 and 20 years.

formed (P = 0.0001) those thinned to 19.5 $m^2 ha^{-1}$ by an average of 25% (Table 2).

Diameter distributions for the largest 247 crop pines ha^{-1} are illustrated in Fig. 1 by thinning treatments at stand ages 16 and 20 years. At 16 years, the normal distributions peaked at 20.3 cm dbh on precommercially thinned plots, compared with 17.8 cm dbh on plots without that treatment. By age 20, dbh growth gains from precommercial thinning were still apparent, and the majority of these pines were approaching sawlog size (> 24 cm dbh) on prethinned plots. Although differences in tree diameters were developing between treatments, the effects of commercial thinning on diameter distributions at age 20 were not as obvious as the effects from precommercial thinning.

Precommercial thinning also tended to improve height growth of crop pines through 20 years. Height gains from precommercial thinning ranged from 2.0 m (P = 0.0002) to 2.2 m (P = 0.0001) for a residual stocking of 494 crop trees ha^{-1} or 19.5 m^2 of basal area ha^{-1}, respectively (Table 1). At 20 years, total height of crop pines on unmanaged control plots did not differ (P = 0.1829) from those on commercially thinned plots. Annual height growth from age 16 to 20 years averaged 11% better (P = 0.0302) when crop pines where thinned to 19.5 $m^2 ha^{-1}$ rather than to 494 crop trees ha^{-1} (Table 2).

As a result of precommercial thinning at age 6, mean crop tree volumes at age 20 had increased by 47% (P = 0.0002) and 40% (P = 0.0004), respectively, on plots thinned to 19.5 $m^2 ha^{-1}$ and on plots thinned to 494 crop trees ha^{-1} (Table 1). At 20 years, there was an average gain of 24% (P = 0.0037) in per-tree volumes for crop pines on thinned plots compared with unmanaged control plots. There was an apparent improvement in mean annual volume growth of crop trees when commercially thinned to 494 crop trees ha^{-1} as opposed to 19.5 m^2 ha-' (Table 2), but the difference between thinning regime means was non-significant (P = 0.0737) at 20 years. As would be expected, crop pines on thinned plots

Table 3
Density, basal area, and volume production in naturally regenerated loblolly-shortleaf pine stands at age 20

Thinning treatment and orthogonal contrast	Density		Basal area ($m^2 ha^{-1}$)	Volume production ($m^3 ha^{-1}$) [a]
	Pines ≥ 9.1 cm dbh (stems ha^{-1})	All pines (stems ha^{-1})		
(1) Unmanaged control	2014	2656	40.40	210
(2) No prethin, commercial thin to 19.5 $m^2 ha^{-1}$ after 16 years	1364	1846	29.61	208
(3) Prethin at 6 years commercial thin to 19.5 $m^2 ha^{-1}$ after 16 years	1045	1421	28.01	189
(4) No prethin, commercial thin to 494 crop trees ha^{-1} after 16 years	667	1107	18.60	208
(5) Prethin at 6 years, commercial thin to 494 crop trees ha^{-1} after 16 years	586	1122	21.81	195
Mean square error	40297	171753	5.93	542
$P > F$ [b]	< 0.0001	0.0051	< 0.0001	0.7297
Treatment contrast	Probability of a greater F [b]			
(1) vs. (2) + (3) + (4) + (5)	< 0.0001	0.0007	< 0.0001	0.5141
(2) + (3) vs. (4) + (5)	0.0005	0.0553	0.0001	0.8062
(2) vs. (3)	0.0818	0.2385	0.4379	0.3332
(4) vs. (5)	0.6262	0.9716	0.1458	0.5011

[a] Volume cut after 16 years + residual volume at 20 years in trees ≥ 9.1 cm dbh.
[b] The probability of obtaining a larger F-ratio under the null hypothesis.

had substantially wider crowns (P = 0.0007) and larger live-crown ratios (***P* = 0.0001**) compared with those on unmanaged controls (Table 1), and precommercial thinning increased live-crown ratios within commercial thinning treatments (P = 0.0001).

3.2. *Stand density, basal area and volume production*

As a result of natural mortality, pine density on unmanaged control plots declined by an average of 24700 stems ha^{-1} between 1982 and 1993. Since survivors on these control plots were principally dominant and codominant trees, 76% had attained merchantable size ($\geq$ 9.1 cm dbh) by age 20 (Table 3). With over 2000 trees ha^{-1}, unmanaged control plots had 120% more ($P < 0.0001$) pines of merchantable size than plots that were commercially thinned after 16 years, and plots thinned to 19.5 m^2 ha^{-1} had 92% more (P = 0.0005) pines than plots thinned to 494 crop trees ha^{-1}.

At 20 years, trends among thinning treatments in pine basal area were similar to those for density (Table 3). Pine basal area averaged highest ($P <$ 0.0001) on unmanaged control plots (40.4 m^2 ha^{-1}) compared with all other treatments (24.5 $m^2 ha^{-1}$). Because of the intensive site preparation that was used in 1971, hardwoods were never a major vegetative component on the study area. At stand age 20, hardwood basal area averaged less than 2 m^2 ha^{-1} on unmanaged control plots.

Plots that were thinned to 19.5 $m^2 ha^{-1}$ after 16 growing seasons averaged 28.8 $m^2 ha^{-1}$ of pine basal area at 20 years (Table 3). That stocking was significantly higher ($P < 0.0001$) when compared with plots thinned to 494 crop trees ha^{-1} (20.2 m^2 ha^{-1}).

At stand age 20 years, total volume production differed by only 21 $m^3 ha^{-1}$ across all thinning treatments (Table 3), and that difference was statistically non-significant (***P*** = 0.7297). However, residual sawlog (> 24 cm dbh) volume at 20 years was substantially improved by precommercial thinning at 6 years (Fig. 2). Precommercial thinning resulted in a 625% increase (P = 0.0310) in sawlog volume on plots cut to 19.5 m^2 ha^{-1} and a 236% increase (***P*** = 0.0077) on plots cut to 494 crop pines ha^{-1}. Within 4 years after commercial thinning, plots thinned to 494 crop pines ha^{-1} averaged 14 $m^3 ha^{-1}$ more (***P*** = 0.0797) sawlog volume than plots thinned to 19.5 m^2 ha^{-1}. At stand age 20, the percent of merchantable-sized pines (> 9.0 cm dbh) that had attained sawtimber size (> 24 cm dbh) were ranked as follows by thinning treatment: NPT/19.5BA

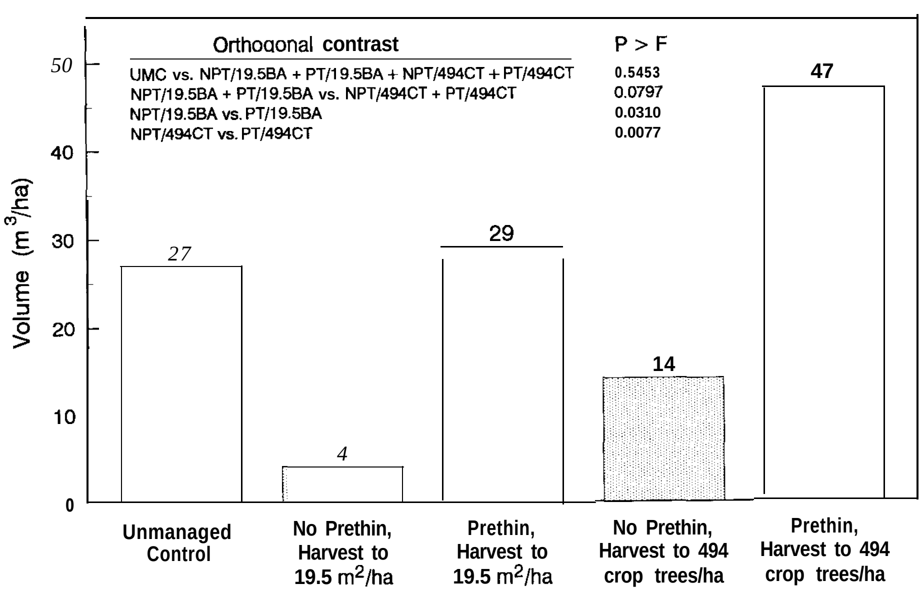

Fig. 2. Merchantable-pine sawlog volume at age 20 by thinning treatments.

(1.2%); UMC (4.4%); NPT/494CT (8.5%); PT/19.5BA (10.2%); PT/494CT (28.3%).

3.3. *Prescribed burning effects*

Fuel and weather variables are presented at ages 17 and 19 years, when the most recent prescribed bums were conducted (Table 4). Because of a greater tonnage of fine fuels from commercial thinning 8 months earlier, fireline intensities tended to average higher during the bum at stand age 17 as compared with the bum at stand age 19. Nevertheless, when the two bums were in progress, the highest mean fireline intensity (602 kW m^{-1}) was recorded at stand age 19 and occurred during a headfire because of a wind shift (Table 4). According to Byram (1959), a fireline intensity of 553 kW m^{-1} is probably near the maximum for headfires or flanking fires that could be used in prescribed burning work. At that intensity, flame lengths average somewhat less than 1.5 m.

Although no pines were killed by these fires, 4% of crop pines were judged to have crown scorch ≥ 90% after the bum at age 17 while 20% of crop pines had ⩾ 90% crown scorch after the bum at age 19. Across all thinning treatments, 46% of crop pines

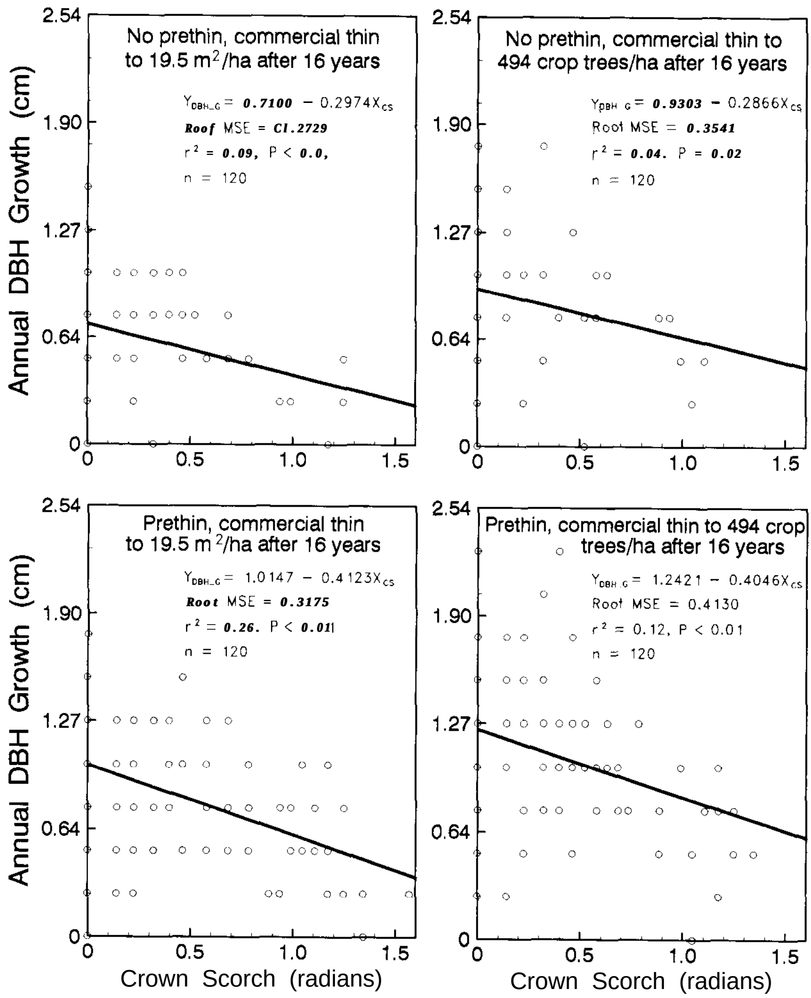

Fig. 3. Impact of crown scorch from a prescribed winter bum on loblolly and shortleaf pine dbh growth from age 17 to 18 years by thinning treatment. X_{cs}, arc sine transformation of % crown scorch using radians.

Table 4
Fuel and weather conditions during prescribed winter bums in naturally regenerated loblolly-shortleaf pine stands at ages 17 and 19 years by thinning treatment

Fuel and weather variables	Thinning treatment by year of bum							
	Stand age 17 years				Stand age 19 years			
	No prethin 19.5 m^2 ha^{-1}	Prethin 19.5 m^2 ha^{-1}	No prethin 494 CT ha^{-1}	Prethin 494 CT ha^{-1}	No prethin 19.5 m^2 ha^{-1}	Prethin 19.5 m^2 ha^{-1}	No prethin 494 CT ha^{-1}	Prethin 494 CT ha^{-1}
Date of bum	12 February 1991				9 February 1993			
Days since last precipitation	7				16			
Time of burning (hours CST)	1330–1500				1045–1230			
Air temperature (°C)	19–18				20-22			
Relative humidity (%)	48-50				30-20			
Wind direction	From the south				From the south and west			
Wind speed (km h^{-1})	6.4				12.9			
Fine fuel moisture (%)[a]	25	26	19	25	18	16	15	20
Dry wt of fine fuel (metric tons ha^{-1})[b]	31	18	34	27	13	9	9	9
Dry wt of heavy fuel (metric tons ha^{-1})[c]	87	13	47	16	Not available			
Rate of spread (m min^{-1})	0.9				0.6[d]-6.1[e]			
Fireline intensity (kW m^{-1})[f]	232	246	211	183	59	149	259	62
Range in fireline intensity (kW m^{-1})	142-353	218–291	90-291	125–246	45-90	38-346	62-602	28-118
Type of bum	Flank fire				Backfire and headfire			

[a] Samples taken in the field from fine-fuel surface litter.
[b] Litter samples and logging slash < 1.4 cm diameter.
[c] Logging slash ≥1.5 cm diameter, from commercial thinning 8 months earlier.
[d] Rate of spread during backfire.
[e] Rate of spread during headfire due to wind shift.
[f] Fireline intensity = 5.67 $L_f^{2.17}$, where L_f is ocular estimate of flame length to nearest 15 cm (Byram, 1959).

were crown scorched during the 17th-year bum and 29% were crown scorched during the 19th-year burn. For those pines with evidence of foliar discoloration, crown scorch averaged 25% and 28%, respectively, following the bums at ages 17 and 19 years.

As crown scorch increased on crop pines in all thinning treatments and regardless of the year of burning, there was a statistically significant ($P <$ 0.05) reduction in dbh growth during the year after each bum (Figs. 3 and 4). Although these regressions are indicative of trends within thinning treatments, low coefficients of determination (r^2 values less than or equal to 0.26) suggest that they are not very useful as precise estimates of dbh growth. After the bum at 17 years, the highest r^2 in these regressions were associated with plots that were precommercially thinned (Fig. 3). After the bum at 19 years, the higher r^2 also tended to occur on plots that were precommercially thinned or commercially thinned to 494 crop trees ha-' (Fig. 4).

3.4. *Vegetative ground cover*

As would be expected, hardwood ground coverage on unmanaged control plots at 20 years averaged

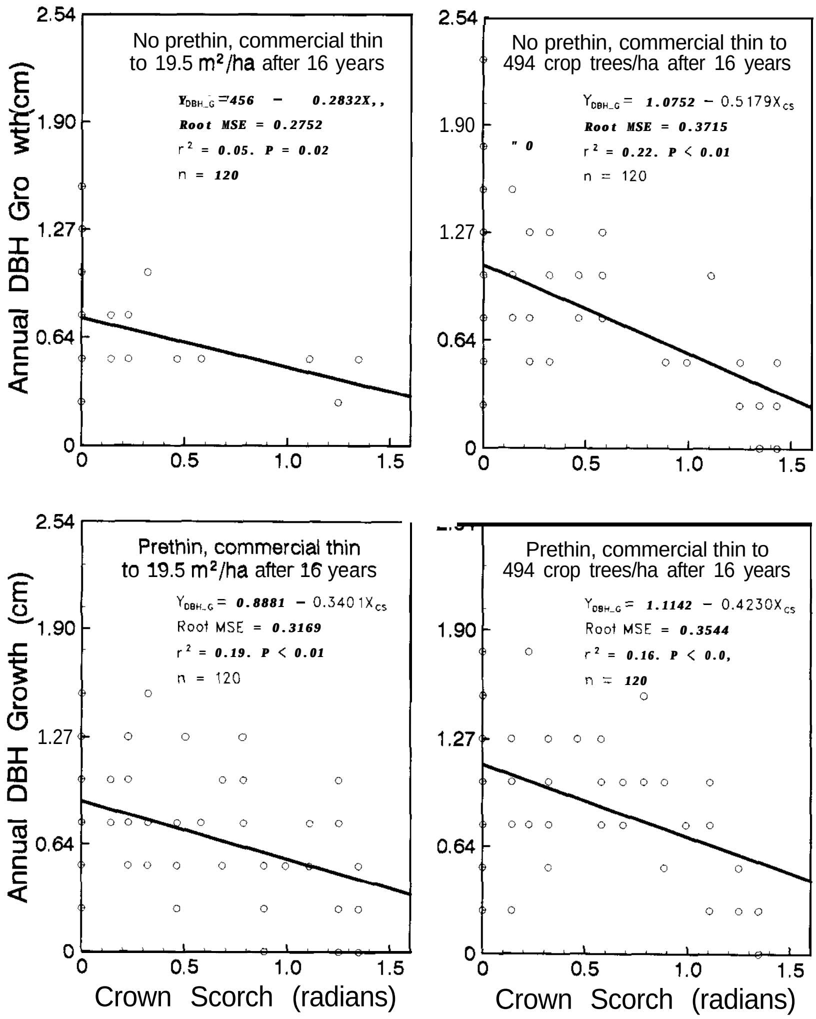

Fig. 4. Impact of crown scorch from a prescribed winter bum on loblolly and shortleaf pine dbh growth from age 19 to 20 years by thinning treatment. X_{cs}, arc sine transformation of % crown scorch using radians.

23% higher (P = 0.0279) than on commercially thinned plots (Table 5), where hardwoods were controlled by stem injection with herbicide 3 years earlier. At 20 years, shrubs-principally *Rhus copallina* and *Vaccinium* spp.-were most prevalent on precommercially thinned plots, where ground coverage averaged from 12% to 13% (Table 5).

Within one growing season after the prescribed bum at stand age 19, grass coverage averaged 44% higher (P = 0.0003) on commercially thinned plots compared with unmanaged control plots (Table 5), where the pine canopy was closed and where no burning occurred. At 20 years, ground coverage from semi-woody plants-principally blackberry (*Rubus* spp.)-averaged highest (> 25% cover with $P <$ 0.02) on plots that were precommercially thinned at stand age 6 (Table 5).

3.5. *Economic returns*

The most intensive thinning regime, i.e. precommercial thinning at age 6 plus commercial thinning to 494 crop pines ha^{-1} after 16 years, resulted in the highest PNV, regardless of the interest rate (Fig. 5). Since there were no costs for precommercial thinning, prescribed burning, hardwood control, or timber sale administration on unmanaged control plots, their PNV at 20 years was the second highest compared with other treatments. However, if the stumpage price of pine pulpwood had been higher in 1989, then the appreciated PNV of control plots would have been less while that of thinned plots would have been higher at age 20.

PNVs for the other three thinning treatments ranked as follows: prethin after 6 years and commercial thin to 19.5 m^2 ha-' after 16 years > no prethin but commercial thin to 494 crop trees ha-' after 16 years > no prethin but commercial thin to 19.5 m^2 ha^{-1} after 16 years (Fig. 5).

4. **Discussion**

Fourteen years after precommercial thinning, the beneficial effects of that treatment on pine diameter growth were still apparent. Although total volume

Table 5
Ground cover by non-pine vegetative components in naturally regenerated loblolly-shortleaf pine stands at age 20

Thinning treatment and orthogonal contrast	Vegetative component				
	Hardwood	Shrub	Graminoid	Semi-woody	Total herbaceous
Ground cover (%)					
(1) Unmanaged control	31.7	0.9	5.1	0.1	39.7
(2) No prethin, commercial thin to 19.5 m^2 ha- ' after 16 years	6.7	1.6	40.3	3.3	47.3
(3) Prethin at 6 years, commercial thin to 19.5 m^2 ha^{-1} after 16 years	6.5	13.0	35.3	25.7	74.0
(4) No prethin, commercial thin to 494 crop trees ha^{-1} after 16 years	12.5	6.8	75.3	10.7	88.3
(5) Prethin at 6 years commercial thin to 494 crop trees ha- ' after 16 years	8.7	12.1	46.7	28.8	84.7
Mean square error	0.02 13	0.0010	0.0186	0.0057	0.0454
$P > F$ [a]	0.2182	0.0021	0.0004	0.0023	0.0077
Treatment contrast	Probability of a greater F [a]				
(1) vs. (2)+(3)+(4)+(5)	0.0279	0.0048	0.0003	0.0054	0.0075
(2)+(3) vs. (4)+(5)	0.6385	0.2719	0.0044	0.2473	0.0099
(2) vs. (3)	0.9847	0.0015	0.6084	0.0043	0.0639
(4) vs. (5)	0.7462	0.0700	0.0060	0.0132	0.5753

[a] The probability of obtaining a larger F-ratio under the null hypothesis.

production in $m^3 ha^{-1}$ averaged somewhat lower on precommercially thinned plots compared with other thinning treatments, sawlog volumes at 20 years were significantly higher as a result of precommercial thinning at stand age 6.

Through age 20, annual volume growth ranged from 9.4 to 10.5 $m^3 ha^{-1}$ across all treatments, which is consistent with expected growth rates on these sites (Grano, 1969). The fact that volumes averaged highest on unmanaged control plots is also consistent with earlier research. For direct-seeded stands of loblolly pine in central Louisiana, Lohrey (1977) reported somewhat higher volumes for all surviving pines on unthinned control plots (254 $m^3 ha^{-1}$) at age 16 when compared with yields from plots that were precommercially thinned (152-230 $m^3 ha^{-1}$) 13 years earlier.

Crop pine crown scorch from prescribed burning varied by thinning treatments. Some of that variation was attributed to the type of fuels that were present. Precommercially thinned plots, for example, were the least disturbed by logging activity during commercial thinning and had an accumulation of tall grasses that were not present on other plots when

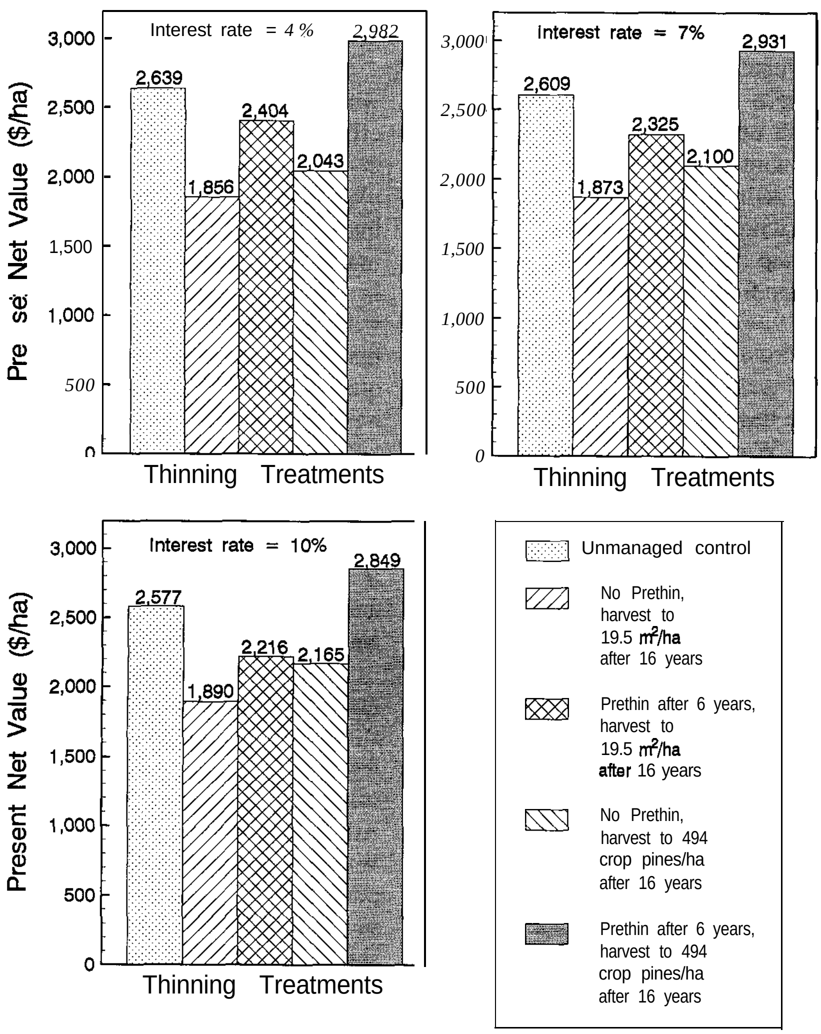

Fig. 5. Present net value of investment in precommercial thinning (age 6), biennial prescribed burning (ages 9–20), and hardwood control (age 18) in naturally regenerated loblolly-shortleaf pine stands through age 20.

burning was done at stand age 17. These grasses tended to be quite flammable during winter because they dry much sooner after winter rains than the ground layer of pine litter and logging slash. Similarly, at stand age 19, plots that were precommercially thinned or commercially thinned to 494 crop trees ha^{-1} had almost complete ground coverage by herbaceous vegetation because of the open stand conditions. After a killing frost in winter, these plants contributed to the fine fuel component which in turn resulted in a higher percentage of crown scorch when burning occurred. In contrast, plots thinned to 19.5 $m^2 ha^{-1}$ without precommercial thinning had almost complete canopy coverage from pines, which reduced the presence of shade-intolerant herbaceous vegetation and lowered the drying potential of surface litter, thereby resulting in minimal crown scorch on crop pines when burning was done during the winter of the 19th year.

Documentation of reductions in pine dbh growth as a result of crown scorch after prescribed burning are not consistent in the literature. By measuring the width of growth rings from increment cores, Waldrop and Van Lear (1984) found no diameter growth loss for trees in codominant and dominant crown classes in 17-year-old unthinned loblolly pine plantations where moderate degrees of crown scorch were reported. However, Wade and Johansen (1986) viewed this anomaly with caution by stating that missing growth rings can be overlooked if the cambium is used as a reference point.

In contrast, Villarrubia and Chambers (1978) found that mean diameter growth decreased with increasing crown scorch in a 20-year-old loblolly pine plantation. They reported that the negative effects of crown scorch on diameter growth were more pronounced in the larger diameter classes as the degree of scorch increased. Similarly, Lilieholm and Hu (1987) found that diameter growth decreased with increasing crown scorch in 19-year-old natural stands of loblolly pines that had been precommercially thinned several weeks before burning by reducing density from 1112 trees ha^{-1} down to 494, 741, and 988 trees ha^{-1}, but growth reductions did not extend beyond 1 year after burning. A preponderance of evidence from these earlier studies and the present investigation suggests that forest managers should try to minimize crown scorch by coordinating their prescribed bums and firing techniques to coincide with appropriate weather and fuel conditions as recommended by Wade and Lunsford (1989).

The variability in non-pine ground coverage suggests that some thinning treatments were more conducive to wildlife habitat than others because of an increase in desirable food plants and protective cover. Precommercial thinning contributed to a greater component of shrubs and semi-woody plants. The two most commonly recurring shrubs were huckleberries (*Vaccinium* spp.) and shinning sumac (*Rhus copallina* L.). Blackberry canes (*Rubus* spp.) were the most common semi-woody plants. All of these species have been identified as important to wildlife in southern forests (Oefinger and Halls, 1974).

Precommercial thinning and biennial prescribed winter bums-between stand ages 9 and 16-were effective in maintaining a mosaic of low-level, horizontal plants that were not present on unthinned plots. Blair and Feduccia (1977) noted that winter bums topkill small hardwoods while stimulating multiple sprouts from the surviving rootstocks, which in turn become a source of cover and forage for wildlife. Stewart (1994) reported that a 2 to 3 year burning rotation provided an acceptable habitat for quail (*Colinus virginianus*), rabbit (*Sylvilagus palustris*), deer (*Odocoileus virginianus*), and turkey (*Meleagris gallopavo*) on southern pine sites, whereas fire exclusion for 5 or more years greatly reduced wildlife habitat quality for these species. Since prescribed burning may contribute to changes in air quality, all burning should be done in accordance with applicable smoke management guidelines and regulations (Wade and Lunsford, 1989).

Landowners can increase their returns on investment by timing harvests to coincide with higher stumpage prices. For example, when the first commercial thinning was done after 16 years, the stumpage price for pine pulpwood in southern Arkansas was only \$14 per 3.6 m^3 (\$ per cord). Within 4 years, that price had increased to \$21.30 per 3.6 m^3 (\$ per cord). Similar fluctuations occur in sawlog prices. During the third quarter of 1993, the stumpage price for pine sawtimber in southern Arkansas ranged from \$39 m^{-3} to \$45 m^{-3} (based on International 0.25-inch log rule).

If landowners were to liquidate their timber assets on a 20-year rotation, then the unmanaged control plots in this study would have been a desirable economic alternative to the other treatments because there were no costs for precommercial thinning, prescribed burning, or hardwood control. In many cases, however, forest landowners have multiple resource objectives, such as enhancing wildlife habitat as well as increasing the economic value of their standing timber by managing for sawlog-size trees. To that end, thinning proved to be an important part of the management strategy in this investigation by producing significantly larger diameter trees by age 20. If present growth trends continue, higher projected stumpage prices for sawlog products will more than offset the costs associated with precommercial thinning or prescribed burning.

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