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Effects of Prescribed Burning or Hexazinone as Release Treatments in a Juvenile Mixed Loblolly Pine-Hardwood Stand.

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EFFECTS OF PRESCRIBED BURNING OR HEXAZINONE AS RELEASE TREATMENTS IN A JUVENILE MIXED LOBLOLLY PINE-HARDWOOD STAND

A Dissertation

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in partial fulfillment of the
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in

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by
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ABSTRACT

A field study was established on a Beauregard silt loam site in central Louisiana to provide basic information on the effects of prescribed burning or hexazinone herbicide when used to control potential competitors of loblolly pine trees (Pinus taeda L.) within a mixed pine-hardwood stand seven years after clearcutting and mechanical site preparation. The design was a randomized complete block, with five blocks of three treatments each: check, hexazinone, and prescribed burn. The burn was a low-intensity winter backfire (87 kJ/s/m) executed on December 20, 1985, after the passage of a cold front, with light northerly winds, relative humidity of 42%, and ambient air temperature of 12°C. The hexazinone was applied on April 12, 1986 at 3.0 kg active ingredient/ha.

The number of suppressed pine trees/ha was greater on the check plots than on the hexazinone and burn plots. Within the hexazinone treatment, the number of potential crop trees decreased significantly after two years. The diameter, height, and stemwood volume growth of the potential pine crop trees was not significantly different among treatments, but within both the hexazinone and burn treatments, the volume/ha of potential crop trees increased significantly over the 2-year period. Therefore, treatments may have affected total stand growth. The insignificant effect of fire on juvenile loblolly pine diameter and height growth is noteworthy, because it shows that cool backfires can be used in relatively young pine stands early in the

rotation without severely injuring the majority of the trees.

The hexazinone treatment reduced the density of oak and the heights and diameters of oak and sweetgum trees. The winter backfire did not lead to a reduction in the brush after two years. However, the first burn in a stand of trees often is limited in effect, which was expected because safety of the potential crop trees from crown scorch and stem injury was of primary concern. Several burns within this juvenile mixed pine-hardwood stand may be needed before the brush is affected significantly.

INTRODUCTION

Interference from hardwood trees and shrubs reduces pine yields on sites targeted for southern pine management (Cain 1988; Glover and Dickens 1985; Grano 1970; Langdon and Trousdell 1974; Zutter et al. 1988a, 1988b). Prescribed burning is an efficient vegetation management practice for hardwood control and fuel reduction in pole-size or larger loblolly pine (Pinus taeda L.) stands (Ferguson 1957, Little and Moore 1949, Lotan et al. 1981), but more and better information is needed on how fire affects the vegetative competition and fuel load associated with southern pine stands of various ages. In particular, few researchers have studied the effects of prescribed burning on juvenile (sapling size or smaller) loblolly pine growth and development, and the use of prescribed fire has been limited in these stands (Lotan et al. 1981, Martin et al. 1979). Due to the damage and loss of small trees associated with wildfire, foresters have focused their attention on prevention and suppression of fire in these stands rather than on the potential benefits of using prescribed fire under selected conditions.

Damage by fire is correlated with the size and degree of fire resistance of the crop species (Greene and Shilling 1987). For example, loblolly pine trees with groundline diameters of 50 mm and under 4 m tall survived fire intensities normally associated with prescribed burning if severe crown scorch was avoided (Cain 1983, Greene and Shilling 1987, Waldrop and Lloyd 1987).

On the other hand, hardwood trees and shrubs of similar size are more susceptible to fire than pine trees, and the smaller the size of the hardwood plant the more effective the burn is in girdling the stem (Ferguson 1957, Greene and Shilling 1987, Grelen 1978, Little and Moore 1949). In theory, the earlier prescribed fire is used in juvenile pine stands, the more efficient the burn should be in controlling hardwood trees and shrubs, and subsequent prescribed burns should be more effective. In addition, fire consumes fuels which reduces the hazard of wildfires. Burning is cheaper than weed control by mechanical methods or use of herbicides (Crow and Shilling 1980, Greene and Shilling 1987).

Herbicides effectively control herbaceous weeds, hardwood trees, and shrubs in juvenile pine stands and have several advantages over prescribed fire. Herbicides can be applied to widely different plant communities of various sizes and under numerous weather conditions. Many types of herbicides and methods of application are available, and thus the silviculturist has control and flexibility when choosing a treatment for a given site. Herbicides are known to be effective for controlling weeds in juvenile pine stands whereas very little is known about the effectiveness of prescribed fire in controlling weeds in juvenile stands.

This study addressed the need to compare prescribed burning with hexazinone for controlling potential competitors of juvenile loblolly pine trees because each practice may be acceptable, but its impact on weed cover, fuel load, and survival, diameter, height, and volume growth of juvenile pine trees may differ. The prescribed burn was a low intensity backfire (87 kJ/s/m) executed after the passage of a

cold front in December, with light northerly winds, relative humidity of 42%, and ambient air temperature of 12°C. The selected herbicide was hexazinone (Velpar[R] L) (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)- dione]. It comes in liquid form and can be applied undiluted to the soil in a uniform grid pattern. Its effectiveness on weeds and tolerance by pine trees makes it a state-of-the-art chemical for controlling the potential competitors of pine trees (Blake et al. 1987; Campbell 1981; Creighton et al. 1987; Fitzgerald and Fortson 1979; Glover et al. 1986; Gonzalez 1980, 1983; Griswold and Gonzalez 1981; Griswold et al. 1984.; Haywood 1980, 1988; Haywood and Melder 1982; McKee and Wilhite 1988; McLemore 1982, 1983; Michael 1980; Miller 1982, 1984, 1988; Minogue et al. 1988; Neary et al. 1981; Nelson et al. 1981; Webb et al. 1981, 1982; Yeiser et al. 1987; Zutter et al. 1988a).

The objectives of this study were:

1. to determine the 2-year effects of prescribed burning or hexazinone herbicide when used to control the potential competitors of juvenile loblolly pine trees, and
2. to compare prescribed burning and the herbicide treatments as methods of controlling the potential competitors of juvenile loblolly pine trees.

REVIEW OF LITERATURE

The Problem

Many diverse plant species occur on southern forest sites after harvesting, site preparation, and planting of pines are completed because these operations reduce, but do not eliminate, late successional tree and shrub species, and they allow the reappearance of native, early successional herbaceous and woody plant species (Swindel et al. 1983). This vegetative cover adversely affects survival and slows diameter and height growth of juvenile pine trees on sites targeted for maximum pine production (Bacon and Zedaker 1987; Cain and Mann 1980; Clason 1978, 1984, 1987; Ferguson 1958; Glover et al. 1986; Tiarks and Haywood 1986).

Grasses are the most productive herbaceous plants on newly established loblolly pine sites in the loblolly pine-shortleaf pine (*P. echinata* Mill.)-hardwood forest type of the southern United States (Wolters and Wilhite 1974). Grasses often hinder conifer establishment and are serious competitors of conifers for the first five growing seasons after planting (McDonald 1986). This is a short-term problem because as stands develop woody vegetation increasingly shades the herbaceous plant cover (Grelen 1976, McDonald 1986). Once competition of herbaceous plants with conifers is reduced, grasses are considered beneficial on good sites with deep soils. Grasses help exclude seedling hardwood trees and shrubs, and conifers are less affected by grasses at this stage of

stand development than by deeper-rooted hardwood stems (Carter et al. 1984, McDonald 1986).

Hardwood trees are long-term competitors of pine trees. Hardwood trees, if left uncontrolled, often become a component of the pine overstory and form a dense understory and second canopy (Haywood 1986) that reduces gains in pine volume and yield (Cain 1988; Glover and Dickens 1985; Grano 1970; Langdon and Trousdell 1974; Zutter et al. 1988a, 1988b). Thus, managers of pine forests attempt to alter early successional vegetation to favor conifer establishment and growth, which can result in early dominance of pine trees with long-term yield benefits (Radosevich and Conrad 1982).

Several vegetation management practices are available for control of undesirable plants in established juvenile loblolly pine stands, such as livestock grazing, manual cutting, disking, mowing, water management, mulching, herbicide application, and prescribed burning. Of these choices, manual cutting, use of herbicides, and prescribed burning are applicable to the widest range of ownership, topography, tract size, difficulty of access, and vegetative cover. Manual brush control is suitable to control brush on small areas. However, manual cutting is generally impractical because the work is labor intensive, productivity is poor, costs are relatively high compared to the use of herbicides or fire, the work is hazardous, and the hardwood stems resprout rapidly (Roberts 1980). Herbicides are more flexible to use than fire.

Hexazinone as a Pine-Release Herbicide

Researchers began to develop a herbicidal replacement for controlling potential competitors of pine trees (pine release) in the southern United States after 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] was banned for forestry uses in 1979. At the beginning of this study, three herbicides were labeled for pine release: dichlorprop [(±)-2(2,4-dichlorophenoxy)propanoic acid], glyphosate [N-(phosphonomethyl)glycine], and hexazinone.

I used hexazinone for loblolly pine release in this study for several reasons. It comes in liquid form and can be applied undiluted to the soil in a uniform grid pattern. It is effective against several hardwood species. For example, researchers have reported that oak (Quercus spp.) topkill ranged from 65 to 100% (Gonzalez 1980, 1983; Haywood 1980; McLemore 1983; Michael 1980; Miller 1982; Neary et al. 1982), sweetgum (Liquidambar styraciflua L.) topkill ranged from 70 to 100% (Gonzalez 1980, 1983; Haywood 1980; McLemore 1983; Miller 1982), blackgum (Nyssa sylvatica Marsh.) topkill ranged from about 37 to 100% (Gonzalez 1983; Grizwold and Gonzalez 1981; Haywood 1980; McLemore 1983; Miller 1982; Webb et al. 1981, 1982), and red maple (Acer rubrum L.) topkill ranged from 25 to 60% (Gonzalez 1983, Griswold and Gonzalez 1981, Haywood 1980, McLemore 1983). Hexazinone can be applied in a juvenile loblolly pine stand without causing severe injury to the pine trees (Blake et al. 1987; Campbell 1981; Creighton et al. 1987; Fitzgerald and Fortson 1979; Glover et al. 1986; Gonzalez 1980, 1983; Griswold and Gonzalez 1981; Haywood 1980, 1988; Haywood and Melder 1982; McKee and Wilhite 1988; McLemore 1982, 1983; Neary et al. 1981; Nelson et al. 1981; Webb et al. 1981, 1982;

Yeiser et al. 1987).

Hexazinone was evaluated for pine release at eight locations in the southern United States (Minogue et al. 1988). Two growing seasons after soil application, hardwood tree and shrub numbers were reduced. The most common species present at treatment were sumac (Rhus spp.), oak, blackgum, hickory (Carya spp.), and Prunus spp. Loblolly pine mortality increased after hexazinone application at some sites, and mortality was inversely correlated with pine tree height. Hardwood control and pine mortality increased as the percent sand content of the soil increased. Thus, soil porosity was important for the lateral movement of the herbicide within the root zone (Minogue et al. 1988).

In another study (Zutter et al. 1988a) of hexazinone, hardwood mortality was 83% with 70% crown reduction three growing seasons after soil application. The major hardwood species present at treatment were sumac, oak, blackgum, hickory, flowering dogwood (Cornus florida L.), and black cherry (Prunus serotina Ehrh.). Five growing seasons after the treatment, average hardwood height and basal area at groundline were respectively 43% and 59% less on treated plots than on the checks, and loblolly pine height and groundline diameter were respectively 24% and 55% greater on treated plots than on the checks (Zutter et al. 1988a).

Miller (1988) used hexazinone as a soil spot treatment for single-stem hardwood control at rates of 0.002-0.007 kg ai for each 25 mm of stem diameter at breast height (dbh = 1.4 m). Hardwood tree topkill ranged from 45 to 97% for sweetgum, 68 to 88% for water oak (Q. nigra L.), and 20 to 92% for flowering dogwood two growing seasons after application.

Hexazinone is thought to be a symmetrical triazine herbicide that is absorbed through the roots or foliage (Minogue 1988). It is translocated through the xylem to the leaves where it apparently acts as a photosynthetic inhibitor. Hexazinone is not toxic to mammals, birds, and fish, but it is slightly toxic to honeybees (Ghassemi et al. 1982, Mayack et al. 1982, Rhodes et al. 1980). It is not carcinogenic, mutagenic, embryotoxic, or teratogenic. Hexazinone has minimum-to-nil effect on microorganisms in soil and water, and it exhibits little potential for bioaccumulation or interruption of the nitrogen cycle.

Nearly all of the hexazinone applied to most forest sites can be expected to enter the soil and be taken up by plant roots or degraded by soil microorganisms (Ghassemi et al. 1982). Hexazinone will move off-site if directly applied over flowing water or via surface runoff, and movement through the soil profile has been detected (Miller and Bace 1980, Neary et al. 1983).

Prescribed Burning as a Pine-Release Treatment

Prescribed burning is a useful vegetation management practice for weed control and fuel reduction (Ferguson 1957, Little and Moore 1949, Lotan et al. 1981). Prescribed fire usually consumes fuels only in the upper layer of litter, and almost no nutrient are lost from the unconsumed fuels comprising most of the forest floor (Hough 1981, Kodama and Van Lear 1980, Richter and Ralston 1982). Prescribed burning has little or no effect on surface soil bulk density, porosity, or percolation rate on forest sites in the southern United States (Grano 1970, Lotti et al. 1960). Low intensity burns have

little effect on ground or stream water quality (Douglass and Van Lear 1983, Richter and Ralston 1982, Van Lear and Danielovich 1988). Neither sediment nor soil export is increased by low intensity burning, and storm flow is similar on burned and unburned watersheds.

By releasing nutrients from burned litter, prescribed fire adds substantial quantities of nonvolatile nutrients to the surface mineral soil and improves soil fertility (Christensen 1977, McKee 1982, McKee and Lewis 1983, McKelvin and McKee 1986, Wells 1971). Periodic winter burning during the rotation before planting may enhance growth of loblolly pine seedlings (McKelvin and McKee 1986). Loblolly growth was also enhanced by planting seedlings in wood ashes from burned windrows in one study (McNab and Ach 1977).

Certain hardwood trees and shrubs are more resistant to fire than others. Repeated burning favors blackjack oak (Q. marilandica Muenchh.), post oak (Q. stellata Wangenh), and hickory (Paulsell 1957). Southern red oak (Q. falcata Michx. var falcata) is less tolerant of fire than hickory or post oak, and sweetgum is less tolerant of fire than oak (Chen et al. 1975, Ferguson 1961). Burning may reduce the numbers of blackgum, flowering dogwood, yaupon (Ilex vomitoria Ait.), southern bayberry (Myrica cerifera L.), and blueberry (Vaccinium spp.) and increase American beautyberry (Callicarpa americana L.), blackberry (Rubus spp.), and greenbrier (Smilax spp.) densities (Lay 1956).

The ability of fire to kill or injure vegetation is influenced by the amount and condition of insulative tissues (bark) and the intensity and duration of the fire (heat factor). The heat factor determines the degree of scorching, leaf consumption, and mortality

the burned vegetation sustains (Lindenmuth and Byram 1948, Greene and Shilling 1987). Conifers tolerate a heat factor of 55°C for 60 seconds (Baker 1929). An equivalent heat factor is 46°C for 1,980 seconds, and loblolly pine tissues die immediately if heated to 65°C (Chapman 1942). Loblolly pine cambium survives brief exposure to fire because pine trees have a thick porous bark that reduces heat conduction and prevents damage (Greene and Shilling 1987). Loblolly pine cambium protected by an 18 mm bark layer is tolerant to fire intensities normally occurring in prescribed burns (McNab 1977). Juvenile loblolly pine trees are better insulated than hardwood trees of the same size, and pine trees tolerate prescribed burning with fireline intensities of 80-100 kJ/s/m better than most hardwood trees if excessive crown scorch is avoided (Greene and Shilling 1987).

The intensities of backfires is greater near the ground than that of headfires; whereas, headfires have a greater intensity above 0.45 m than backfires (Lindenmuth and Byram 1948). Thus, low intensity backfires are a promising tool for use in dense stands of juvenile pines because the pine cambium is better insulated near the ground and the potential for crown scorch is reduced (Cain 1983; Greene and Shilling 1987; Johansen and Wade 1987; McNab 1977; Silker 1953; Waldrop and Lloyd 1987, 1988). Loblolly pine with groundline diameters of 30-40 mm tolerated backfires of under 80 kJ/s/m, and pine trees with diameters of at least 50 mm tolerated backfires of 98 kJ/s/m (Greene and Shilling 1987).

When fire is improperly used, crown scorch, resulting in the death of buds and branch cambium, is the chief cause of mortality among pine trees over 50-75 mm in dbh (Wade and Johansen 1986), and severe crown

scorch will decrease the growth rate of pine trees (Allen 1960, Cooper and Altobellis 1969, Hare 1961, Lilieholm and Hu 1987, Villarrubia and Chambers 1978, Waldrop and Lloyd 1988).

As hardwood trees and shrubs grow their resistance to heat injury increases (Ferguson 1957, Greene and Shilling 1987, Grelen 1978, Little and Moore 1949). Backfires of 64 kJ/s/m intensity were ineffective on water oak and sweetgum with groundline diameters of 70-80 mm, but backfires of 98 kJ/s/m intensity deadened 40% of the water oak and 50% of the sweetgum within this diameter range and scarred the stem of most surviving trees (Greene and Shilling 1987).

Hardwood stems less than 25 mm in dbh are controlled equally well by backfires and strip headfires regardless of burning season (Brender and Cooper 1968). However, control of hardwood stems with dbh over 25 mm is influenced by the kind and timing of burning. The first burn of the rotation is usually an initial low intensity winter-burn that rarely kills root systems, although the above-ground portions of small hardwood stems are likely to be killed (Chen et al. 1975, Greene and Shilling 1987). The roots readily regenerate new shoots after burning (Ferguson 1957, Elliott and Pomeroy 1948), and numbers of hardwood trees and shrubs less than 2 m tall may actually increase after fire (Hodgkins 1958), but the average height of all stems and individual stem vigor will be reduced (Lotti 1956, Silker 1961, Yocom 1972).

The desire to control woody competitors with fire must be balanced against the need to protect the potential pine crop trees from excessive crown scorch and stem injury. Therefore, the prescribed method of burning in this study was a low intensity backfire. This technique usually concentrates the fire's intensity nearer the ground

where the bark of the pine stems is thickest and less crown scorching should result.

Prescribed Burning and Herbicide Comparisons

Prescribed burning or herbicides may be acceptable methods of controlling brush in juvenile stands of loblolly pine in the southern United States, but the need exists to compare prescribed burning to herbicide applications for controlling potential competitors of loblolly pine trees because their impacts on vegetative cover, fuel load, and survival and development of juvenile pine trees is unknown. Several researchers have compared prescribed burning and herbicides as hardwood control treatments (Bragg and Hulbert 1976, Chen et al. 1975, Gordon et al. 1982, Mayeux and Hamilton 1983, Tappeiner 1979). Burning is an effective short-term treatment that must be applied periodically or the benefits are lost. Herbicides provide longer control of certain plant species because they can more effectively kill root systems. Herbicides are not, however, effective on all undesirable species, even if reapplied. Herbicides can be detrimental to desirable trees under certain conditions.

Initially, plant mortality from herbicide use increases the amount of dead fuels, but fuel levels return to normal as the deadened vegetation decays, and in the long-term, the amount of woody fuels may decrease (Loomis and Crosby 1968). Prescribed burning initially reduces the amount of fine fuels (Deeming et al. 1972, Johansen et al. 1976), but sprouting may restore the fuel load to preburn conditions unless fire is used again. As with herbicides, death of some of the larger woody plants from burning may temporarily increase dead fuels.

Prescribed burning with and without the application of hexazinone was used in an uneven-aged shortleaf pine-hardwood stand in Oklahoma (Nickles et al. 1981). Most of the pine trees were less than 12 m tall. Because all plots were burned, a fire vs. chemical only comparison could not be made. Hexazinone application prior to burning increased combustable fuels, and a greater fire intensity resulted with more pine injury. The injury was greatest among shortleaf pine less than 28 mm in groundline diameter and less than 2 m tall. Hexazinone with fire effectively controlled the hardwood trees.

Hexazinone and prescribed burning were tested as site preparation treatments for loblolly pine on a site in the Alabama Piedmont (Miller 1982). Hexazinone application caused the topkill of much of the hardwood overstory and increased combustable fuels. Its use before burning increased the topkill of the hardwood overstory. Prescribed burning alone was ineffective on large stems, but preharvest burning, without hexazinone application, effectively reduced the numbers of sprouts, hardwood seedlings, and shrubs on the site.

Thus, prescribed burning or hexazinone might be acceptable for controlling potential competitors of juvenile loblolly pine trees, but the risks each poses to the pine stand, their effectiveness in competition control, and impacts on fuels may differ. My research provided basic information on the effects of hexazinone or burning on pine survival, hardwood mortality, and fuel levels.

METHODS AND PROCEDURE

Study Area

The study area was on an 8-ha site on the Kisatchie National Forest, Evangeline Ranger District, sections 19 and 30, R3W T3N, compartment number 23, stand number 11, Rapides Parish, Louisiana (Figure 1). The soil type, a Beauregard silt loam (Plinthaquic Paleudult, fine-silty, siliceous, thermic), is low in natural fertility with slow surface runoff and water movement through the profile (Kerr et al. 1980). The site is usually wet from December through April due to a perched water table within 2 m of the surface. Wetness during the growing season is the main limitation on agricultural suitability, but plant vigor is likely to be limited by a lack of available moisture during droughts in the summer and fall. Kerr et al. 1980 classed the soil as productive for pine trees with a site index at age 50 of 27.4 m (90 feet).

The following information on stand establishment was extracted from the USDA Forest Service, Plan and Map Record.[1/]

> The previous forest stand was clearcut followed by chop and burn site preparation in the summer of 1978. In February 1979, the tract was direct seeded from a helicopter at a rate of 1.3 kg/ha of loblolly pine seed. Conditions for direct seeding were described by Kisatchie National Forest personnel as clean with exposed mineral soil. However, the reproduction was judged a failure in 1979 by Kisatchie National Forest personnel. In

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[1/] USDA Forest Service. 1979. Plan and map record. USDA For. Serv., Kisatchie National For., Evangeline Ranger Dist., Compartment no. 23, Stand no. 11.

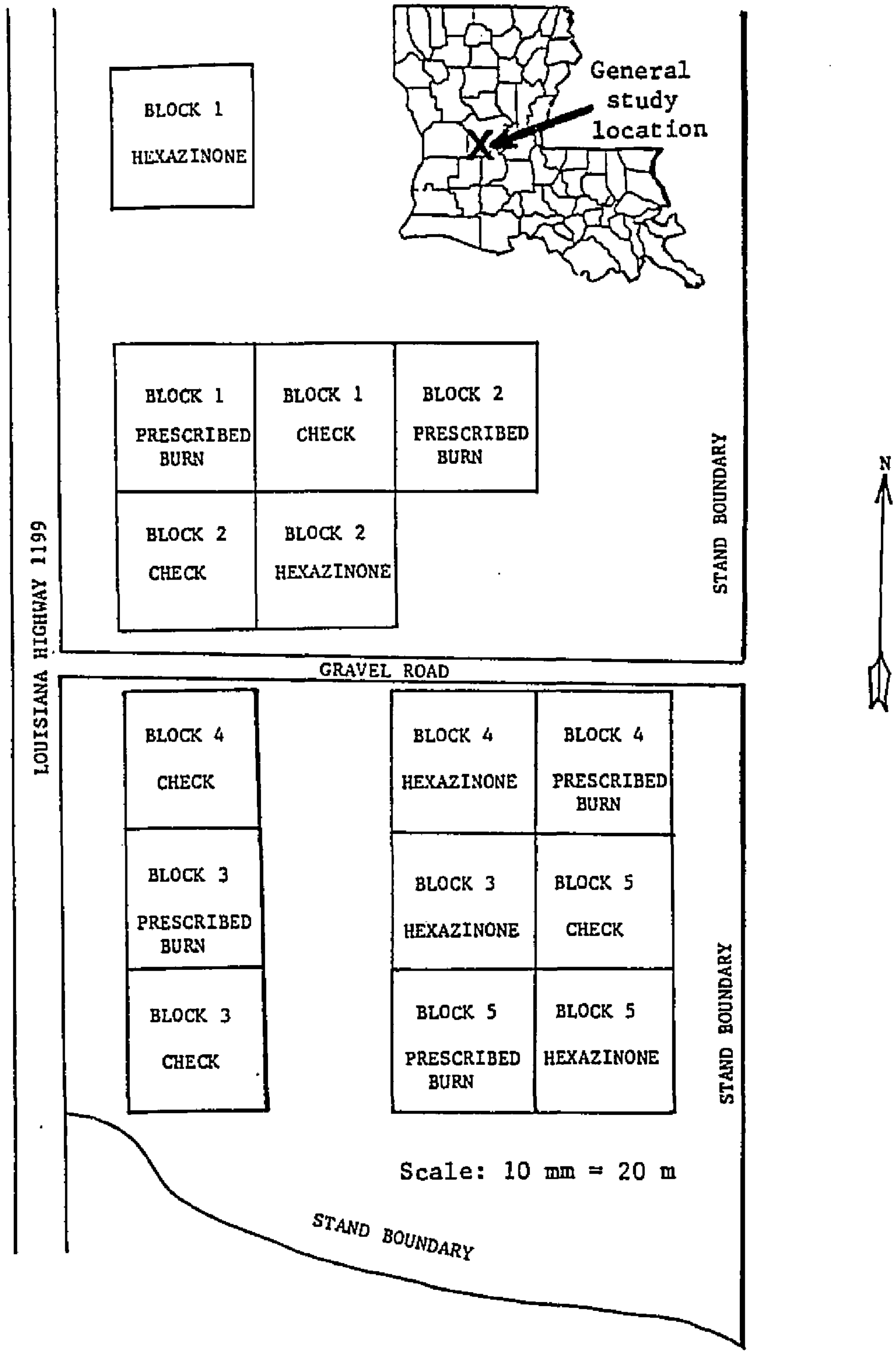

Figure 1. Randomized complete block design layout of the study.

February 1980, 1-0 loblolly pine seedlings were dibble-planted into a tall grass cover at a 1.8 x 3.0 m spacing (1,794 trees/ha). Water was standing on the site during planting and the ambient air temperature reached 27-32°C. In December 1980, Kisatchie National Forest personnel determined planted pine survival to be 29% (500 trees/ha). However, the site was considered 91% stocked (1,350 trees/ha) when natural, direct-seeded, and planted pine seedlings were combined. The stand was classified as a plantation by Kisatchie National Forest personnel in 1980.

This study was initiated in 1984, approximately seven growing seasons after site preparation. The planting-rows were indistinguishable, and loblolly pine density averaged 2,825 trees/ha, which was well above 100% stocking.

In 1984, hardwood trees numbered 9,200 stems/ha. Sweetgum was the most common in mixture with blackgum, red maple, southern red oak, water oak, live oak (Q. virginiana Mill.), and post oak. Other hardwood trees included black cherry, winged elm (Ulmus alata Michx.), common persimmon (Diospyros virginiana L.), sassafras (Sassafras albidum (Nutt.) Nees), fringetree (Chionanthus virginicus L.), American holly (Ilex opaca Ait.), and southern magnolia (Magnolia grandiflora L.). Shrubs numbered 18,000 stems/ha and included southern bayberry, American beautyberry, blueberry, eastern baccharis (Baccharis halimifolia L.), shining sumac (Rhus copallina L.), common privet (Ligustrum vulgare L.), yaupon, and hawthorn (Crataegus spp.). Blackberry was very common (3,900 canes/ha), as were several vines: Carolina jessamine (Gelsemium sempervirens (L.) Ait. f.), Alabama supplejack (Berchemia scandens (Hill) K. Koch), muscadine grape (Vitis rotundifolia Michx.), greenbrier, cross-vine (Bignonia capreolata L.), poison-ivy (Toxicodendron radicans (L.) Kuntze), and Japanese honeysuckle (Lonicera japonica Thunb.).

Study Design

Fifteen plots were installed in June 1984 in a randomized complete block design: 5 blocks of 3 treatments each, check, hexazinone, and burn (Figure 1). Each treatment plot was 40 x 40 m (0.16 ha) and data was collected within a 30 x 30 m (0.09 ha) interior measurement plot (Figure 2). Each treatment plot was bordered by a 3-m wide buffer strip (#7, Figure 2) that was disked each year for a firebreak. The blocking was based on vegetation data collected in September 1984 (Table 1). In order of importance, the criteria for blocking were: (1) numbers of hardwood trees at least 1.4 m tall, (2) numbers of all hardwood trees, (3) numbers of pine trees at least 1.4 m tall, and (4) numbers of all pine trees.

Sampling Procedures

Plant cover. Plant cover included all above ground vegetation on the site. The plant cover was measured before and two growing seasons after treatments. Five 4-m^2 circular vegetation-sampling plots were permanently established every 6 m along five line transects (#1, Figure 2) systematically located across each 30 x 30 m interior measurement plot (#2, Figure 2) (Butler and McDonald 1983). The point of origin for the first transect was randomly located on the west side of each interior plot. The other four transects were placed 5 m apart and parallel to the first transect. All transects extended in an East-West direction across the interior plot. The center of each vegetation-sampling plot was marked with a yellow steel rod. This arrangement resulted in 25 permanently located vegetation- sampling plots within each interior plot (#2, Figure 2).

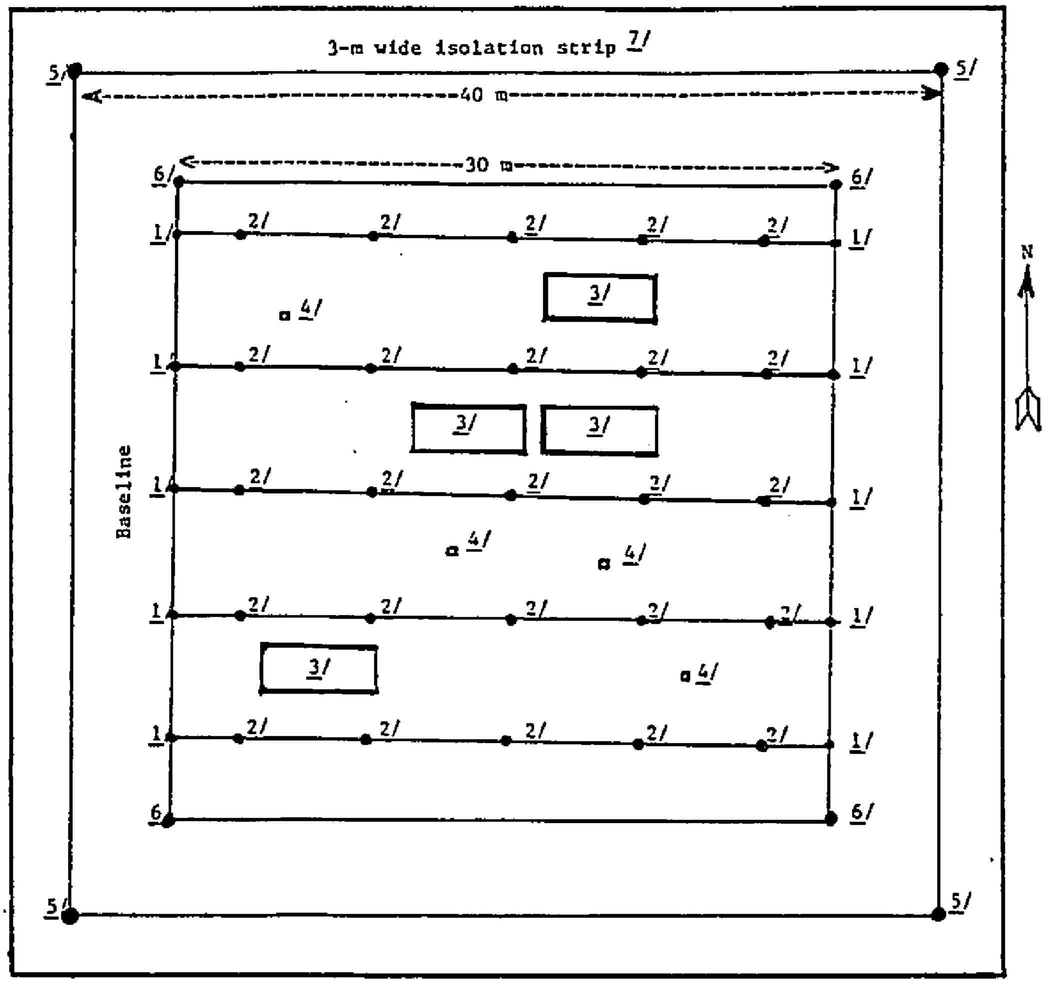

Figure 2. Diagram of one 40 x 40 m treatment plot and a 30 x 30 m interior measurement plot.

1/ Systematic locations of the 5 transects that extend in an East-West direction across the interior plot.

2/ Permanently established centers for the 25 circular vegetation-sampling plots.

3/ Random locations for the four permanent 2 x 5 m fuel-sample plots.

4/ Random locations for the four 0.3 x 0.3 m fuel-moisture plots, on the prescribed burned plots only.

5/ Locations of the wooden stakes at each corner of the treatment plot.

6/ Locations of the steel rod at each corner of the interior plot.

7/ A 3-m wide isolation strip was left around each treatment plot.

Table 1. Average density by species group and size before treatments were applied.

Treatments	Hardwood trees: Stems ≥ 1.4 m tall	Hardwood trees: All stems	Loblolly pine: Stems ≥ 1.4 m tall	Loblolly pine: All stems	Combined species: Stems ≥ 1.4 m tall	Combined species: All stems
	(stems/ha)					
Block 1						
Check	2,700	6,600	1,200	2,300	3,900	8,900
Hexazinone	3,100	6,100	700	2,100	3,800	8,200
Burn	4,000	7,200	1,200	2,300	5,200	9,500
Mean	3,267	6,633	1,033	2,233	4,300	8,867
Block 2						
Check	2,300	4,700	1,200	2,300	3,500	7,000
Hexazinone	2,500	4,300	1,700	2,700	4,200	7,000
Burn	2,000	4,200	600	1,600	2,600	5,800
Mean	2,267	4,400	1,167	2,200	3,433	6,600
Block 3						
Check	6,700	9,000	1,800	3,900	8,500	12,900
Hexazinone	5,400	8,000	1,300	2,700	6,700	10,700
Burn	6,200	7,700	800	2,700	7,000	10,400
Mean	6,100	8,233	1,300	3,100	7,400	11,333
Block 4						
Check	7,200	8,600	1,700	2,400	8,900	11,000
Hexazinone	7,800	10,900	2,200	3,300	10,000	14,200
Burn	8,700	10,100	1,100	1,700	9,800	11,800
Mean	7,900	9,867	1,667	2,467	9,567	12,333
Block 5						
Check	7,400	17,300	2,700	5,000	10,100	22,300
Hexazinone	7,300	10,700	2,100	4,700	9,400	15,400
Burn	7,200	12,400	2,500	3,600	9,700	16,000
Mean	7,300	13,467	2,433	4,433	9,733	17,900

Within each vegetation-sampling plot, percentage of the surface covered by herbaceous plants or vines was estimated to the nearest percent. Blackberry canes were counted and their mean height was estimated to the nearest 10 mm. All pines, hardwood trees, and shrubs were identified by species, and groundline diameters were measured with calipers to the nearest mm. Total heights were measured with a height pole to the nearest 10 mm for pines, hardwood trees, and shrubs less than 1.4 m tall and to the nearest 30 mm for those at least 1.4 m tall. The dbh was measured to the nearest mm for pine and hardwood trees at least 1.4 m tall. Only those stems whose pith was within the vegetation-sampling plot were measured.

Height of pine and corresponding dbh data were used to calculate the inside-bark volume of pine stems at least 1.4 m tall with Schmitt and Bower's (1970) formula. Volumes of hardwood stems were not calculated and the dbh data for hardwoods were not used because of the generally small size of the hardwood trees and shrubs.

Each pine tree was assigned to one of two classes based on its perceived potential to capture a place in the crown canopy (Zutter et al. 1985). The tree classes were: (1) Potential crop trees-- pine trees that may reach merchantable size, trees that are free-to-grow or intermediate trees that have at least a 10% chance of capturing a place in the crown canopy and (2) Suppressed pine trees-- pine trees that are over-topped by other woody plants, and there is less than a 10% chance that they will capture a place in the crown canopy.

Fuel load sampling. To determine changes in the amounts of fuels on all treatments, four 2 x 5 m fuel sample plots (#3, Figure 2) were randomly selected and permanently established within each interior measurement plot. None of the fuel sample plots overlaid a vegetation-sampling plot. Each fuel sample plot was divided into 10 randomly numbered 1-m^2 subplots for sampling fuel load without replacement. For each plot, fuel samples were collected at the end of each growing season, and on the burn plots, fuel samples were also collected in January 1986 following burning.

In this study, only three sizes and types of fuels were considered available for combustion (see Deeming et al. 1972, Fosberg et al. 1970, Fosberg and Deeming 1971, Johansen et al. 1976). These three fuel classes were as follows: (1) living foliage of all trees, shrubs, vines, grasses, and forbs, (2) the 1-h timelag dead fuels (surface litter and duff, small roundwood, and stubble no more than 6 mm in diameter), and (3) living blackberry canes, woody stems, and vines no more than 6 mm in diameter. The three classes of fuels were expected to have the following moisture contents on a dry weight basis: (1) 50-80% for the foliage of all trees, shrubs, vines, grasses, and forbs (Deeming et al. 1978), (2) 8-15% for the surface litter and duff, roundwood, and stubble no more than 6 mm in diameter (Blackmarr 1971), and (3) 80-110% for the living blackberry canes, woody stems, and vines no more than 6 mm in diameter (Deeming et al. 1978). The sampled fuels from each plot was separated into these fuel classes before determining oven-dry weights.

Details for the Three Treatments.

Check. No treatment was applied.

Prescribed burn. The type of fire prescribed was a low intensity backfire with an expected range in fire intensities of 0-170 kJ/s/m (Deeming et al. 1978) and a planned average fire intensity of about 70 kJ/s/m (Brender and Cooper 1968). To obtain this burn, certain weather conditions were necessary: a passage of a cold front with some rain, followed by a steady northerly wind, and a relative humidity of 50%.

On December 20, 1985, the stand and weather conditions were judged desirable to execute the proper prescribed burn. It had rained 89 mm between December 12-15, 1985, and the fuels were judged to have dried sufficiently. Test fires were set to ensure that burning conditions were acceptable before the plots were burned.

The backfires were set with a standard drip torch. During burning, temperature and wind speed readings were taken at a height of 2 m about every 15 minutes. The ambient air temperatures varied from 11-13^{o}C for all five blocks. Skies were clear. The relative humidity varied from 54% at 11:00 AM when the first backfire was set to 34% at 2:00 PM when the last backfire was finished, and averaged 42% for the 3-h period. The wind was northerly at 0-32 kmph with an average speed of 9 kmph. The backfire produced an acceptable fire intensity (87 kJ/s/m) based on Byram's fire intensity (Byram 1959, Alexander 1982) and resulted in very little crown scorch among the potential crop trees.

Just prior to backfiring, a sample of the fuels was collected on four randomly located 0.3 x 0.3 m fuel-moisture plots in the interior

of each burn plot (#4, Figure 2) as done by Smith and James (1978). These plots were distinct from the fuel sample plots and the vegetation-sampling plots described previously. The samples were used for determining available fuel moisture on a dry weight basis for each fuel class.

Byram's fire intensity (I=Hwr) was determined to provide a quantitative expression of fire behavior (Byram 1959, Alexander 1982): I is fire intensity in kJ/s/m, r is the rate of spread in m/s, w is fuel consumed in kg/m^2, and H is the low heat of combustion of fuels in kJ/kg. H is corrected for the heat lost in drying.

H was calculated as follows: 19,254 kJ/kg - 24 kJ/kg/percent of moisture on a dry weight basis by fuel class (Alexander 1982, Hough 1969). H was weighted to account for differences in fuel consumption and fuel moisture among the three fuel classes. Fuel consumption was based on the differences in oven-dry weights of fuel collected in September 1985 vs. January 1986.

Hexazinone. On April 17, 1986, the herbicide hexazinone was applied with a metered spotgun applicator at a rate of 2 ml of Velpar[R] L/spot. Velpar[R] L is a tradename for hexazinone. The spots were spaced about 1-2 m apart over the entire 40 x 40 m plot surface. The mean rate of application was 3.0 kg ai/ha of hexazinone and was 89% of the manufacturer's recommended rate of 3.36 kg ai/ha given on the label.

At the time of application, the soil was moist from a 12-mm rain on April 12, 1986, but there was no standing water. The hexazinone was applied under clear skies with an ambient air temperature of

21-26^{o}C. Foliage on the hardwood trees and shrubs was almost, or already, fully extended, and the leaves were still light-green in color. However, a large amount of surface litter kept some of the herbicide from immediately reaching the soil surface. It rained 37 mm on April 19-20, 1986, a sufficient amount to move the herbicide into the soil.

Vegetative and soil conditions on the day the hexazinone was applied, the amount of herbicide applied, and the slow rainfall two and three days after application were optimum for herbicide treatment and efficacy.

Data Analysis

Before and two growing seasons after treatments, data were collected on the vegetation-sampling plots and the fuel sample plots to provide mean plot values for analysis. The check treatment in block 3 was burned during a wildfire on March 25, 1986, and the data from this plot were excluded from the analyses.

Before the treatments were applied, treatment differences were tested by analysis of variance ($P = 0.05$) (SAS Institute Inc. 1985). Two growing seasons after treatments, analysis of covariance was used to determine treatment differences, with the corresponding before-release data being used as the covariate. Treatment differences for mean changes over the 2-year study were compared by analysis of variance. The treatment effects were considered fixed because the method of prescribed burning and the use of hexazinone herbicide were selected from among many possible vegetation management

practices (Steel and Torrie 1980). The block effects were considered random. The complete model was:

$$Y_{ij} = u + T_i + B_j + R(Y_{ij}:X_{ij}) + E_{ij}$$

where

Y_{ij} = the value of the ith treatment of the jth block,

u = the overall mean for all observations,

T_i = the effect of the ith treatment,

B_j = the effect of the jth block,

$R(Y_{ij}:X_{ij})$ = the regression of Y_{ij} on X_{ij} where Y_{ij} is the after-release data and X_{ij} is the corresponding before-release data used as the the covariate, and

E_{ij} = experimental error (residual).

The null hypothesis for testing treatment differences was: there are no differences among treatments (P = 0.05). Duncan's Multiple Range Tests were used to determine treatment differences, if the null was rejected. For each statistical test, the probability of a greater F-value is reported to aid forest managers whose decisions might be based on different criterion of significance than I used.

For loblolly pine trees, the number of trees/ha, groundline diameter, and height were analyzed by tree class. For pine trees at least 1.4 m tall, stemwood volume/tree and volume/ha data were also analyzed by tree class.

The hardwood data were initially to be analyzed by three groundline diameter classes: 0-25 mm, 26-50 mm, and over 50 mm. However, the hardwood trees and shrubs were very uniform in diameter,

so all stems were combined by species group. For the hardwoods, the number of stems/ha, groundline diameter, and height data were analyzed for all hardwood trees and separately for sweetgum, oak, red maple, blackgum, other hardwood trees, and shrubs. The number of blackberry canes/ha and height of blackberry, the percent surface cover of herbaceous plants, percent surface cover of vines, and the oven-dry weights of fuels were also analyzed.

Within treatment, the data before treatment and two growing seasons after treatment were compared with a Student's t-test to determine if significant changes occurred over the 2-year period ($P = 0.05$) (SAS Institute Inc. 1985). Among treatments, chi-square tests were used to determine if the treatments influenced the distribution of groundline diameters and heights of loblolly pine trees ($P = 0.05$) (SAS Institute Inc. 1985).

RESULTS AND DISCUSSION

Burning Conditions

The backfires averaged 87 kJ/s/m, which is within the range of fire intensities reported by others as being used successfully in loblolly pine stands (Blackmarr 1971, Brender and Cooper 1968, Deeming et al. 1978, Greene and Shilling 1987) (Table 2). Across blocks, consumption of all fuels ranged from 0.0398 to 0.4460 kg/m^2 and averaged 0.2132 kg/m^2. The differences in fuel consumption were most responsible for the range in fire intensities among blocks. Rate of spread averaged 0.025 m/s and ranged from 0.020 to 0.035 m/s. The low heat of combustion of all fuels averaged 17,101 kJ/kg and ranged from 16,663 to 17,851 kJ/kg.

The foliage of all trees, shrubs, vines, grasses, and forbs were the fuels that contributed most (83 kJ/s/m) to the total fire intensity (Table 2). A high average moisture content of these fuels (100%) resulted in a low heat of combustion of 16,863 kJ/kg. However, fuel consumption ranged from 0.0728 to 0.4075 kg/m^2 among blocks, and 50-93% of the available fuels were consumed.

The litter, roundwood, and stubble had an average moisture content of 54% (Table 2). However, fuel consumption was low, and it ranged from -0.0600 to 0.1170 kg/m^2 across blocks. Therefore, the consumption of fuels was below detectable levels on some blocks. The fire intensity averaged 7 kJ/s/m.

Table 2. Fire behavior data used to calculate Byram's fire intensity (I=Hwr) for the December 20, 1985, prescribed burns.

Block	Rate of spread (r) (m/s)	Fuels available for burning (kg/m^2)	Fuels consumed (w) (kg/m^2)	Moisture content by dry weight (%)	Low heat of combustion (H) (kJ/kg)	Fire intensity (I) (kJ/s/m)
	All Fuel Groups					
1	0.026	0.5878	0.2481	98	16,960	111
2	0.021	0.6329	0.2129	71	17,113	75
3	0.035	0.6765	0.1194	68	16,916	69
4	0.020	0.7170	0.0398	66	17,851	17
5	0.022	0.7008	0.4460	83	16,663	165
Mean	0.025	0.6630	0.2132	77	17,101	87
	Foliage of All Trees, Shrubs, Vines, Grasses, and Forbs					
1	0.026	0.1729	0.1534	110	16,608	67
2	0.021	0.2441	0.1743	100	16,849	61
3	0.035	0.2034	0.1885	100	16,837	111
4	0.020	0.1445	0.0728	76	17,424	26
5	0.022	0.4410	0.4075	111	16,597	150
Mean	0.025	0.2412	0.1993	100	16,863	83
	Litter, Roundwood, and Stubble no more than 6 mm in Diameter					
1	0.026	0.1004	0.0239	90	17,091	14
2	0.021	0.1874	-0.0600	43	18,214	- 23
3	0.035	0.1019	0.0107	36	18,401	7
4	0.020	0.2129	0.1170	48	18,113	42
5	0.022	0.0857	-0.0102	54	17,968	- 4
Mean	0.025	0.1377	0.0163	54	17,957	7
	Living Blackberry, Woody Stems, and Vines < 6 mm in Diameter					
1	0.026	0.3145	0.0708	92	17,050	31
2	0.021	0.2014	0.0986	70	17,582	36
3	0.035	0.3712	-0.0798	67	17,649	- 49
4	0.020	0.3596	-0.1500	75	17,457	- 51
5	0.022	0.1741	0.0488	85	17,202	19
Mean	0.025	0.2842	-0.0023	78	17,388	- 3

Across blocks, the moisture content of the living blackberry, woody stems, and vines was 78%, which was the expected moisture content for these fuels (Deemings et al. 1978). However, the average fire intensity for these living fuels was -3 kJ/s/m, making these fuels below detectable levels of consumption.

Fuel dispersion was very variable over the plot surfaces. There were areas of standing grasses, forbs and stubble interspersed with clumps of trees with leaf litter and duff underneath. The litter was wet in places, and there was some puddling due to the rain 5 days before. Therefore, the backfires had to be reset continually to burn these fuels. The conditions that necessitated the resetting of the fires also helped keep the flame heights low, so there was very little crown scorch among the potential crop trees.

Fuel Consumption

The fuels available for combustion decreased by 1,147 kg/ha on the burn plots 2-years after treatment, whereas these fuels increased by 35 kg/ha on the check and 3,265 kg/ha on the hexazinone plots (Table 3). However, these treatment means were not significantly different.

Loblolly Pine

Before and after treatments, the number of potential crop trees/ha was not significantly different among treatments, and during the 2-year study, the density decreased similarly across treatments: -16% on the check, -22% on the hexazinone, and -23% on the burn plots (Table 4). However, within the hexazinone treatment, the decrease in the number of potential crop trees after two years was significant.

Table 3. Oven-dry weights of fuels available for burning before and two growing seasons after treatments.

Measurement period	Treatments			Prob. > F
	Check	Hexazinone	Burn	
	(kg/ha)			
Before	7,530 (2,479)[1/]	4,148 (1,327)	6,630 (526)	0.0761
After	7,565 (3,554)	7,413 (4,356)	5,483 (2,203)	0.7548
Change	+35 (2,167)[2/]	+3,265 (2,036)	-1,147 (1,013)	0.3802
Prob. > t	0.9877	0.1736	0.3155	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

Table 4. Average density of loblolly pine trees before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	(trees/ha)			
	Potential crop trees			
Before	1,825 (655)[1/]	1,820 (259)	1,460 (627)	0.2094
After	1,525 (499)	1,420 (268)	1,120 (363)	0.4901
Change	-300 (412)[2/]	-400 (167)	-340 (324)	0.4873
Prob. > t	0.4937	0.0432 *	0.3247	
	Suppressed trees			
Before	1,550 (465)	1,600 (977)	1,440 (397)	0.9229
After	1,725 A[3/] (585)	1,260 B (467)	1,000 B (406)	0.0027
Change	+175 (374)	-340 (484)	-440 (254)	0.3023
Prob. > t	0.6563	0.5026	0.1217	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

* Within treatment, the before and after treatment densities are significantly different (P = 0.05), based on Student's t-test.

3/ Within rows, treatment means followed by the same letter are not significantly different (P = 0.05), based on Duncan's Multiple Range Test.

Also, I believe the decrease in number of pine crop trees was most uniform among the hexazinone plots, as suggested by the standard deviations.

Before treatments, the number of suppressed pine trees was not significantly different among treatments. After treatments, suppressed tree density increased 11% on the check plots, but decreased 21% on the hexazinone and 31% on the burn plots (Table 4). Thus, the hexazinone and burn plots had significantly fewer suppressed trees than the checks two growing seasons after treatments: 1,260 trees/ha on the hexazinone and 1,000 trees/ha on the burn plots vs. 1,725 trees/ha on the check plots (Tables 4 and 18). The hexazinone and burn plots had similar numbers of suppressed pine trees/ha. Thus, both treatments were successful in reducing the number of suppressed trees, but neither treatment was more successful than the other. This might decrease intraspecfic competition with the potential crop trees, but suppressed trees are not normally major competitors.

Before treatments, the groundline diameter distribution of loblolly pine trees was concentrated in the smaller diameter classes (a reverse-J curve), and 25%, 29%, and 33% of the trees were in the 0-9.9 mm class for the check, hexazinone, and burn plots, respectively (Figure 3). Two growing seasons after treatment, however, the diameter distribution was more evenly distributed for all three treatments. Still, 12%, 11%, and 8% of the trees remained in the 0-9.9 mm class for the check, hexazinone, and burn treatments, respectively. Both before and after treatments, the diameter distributions were similar for all treatments.

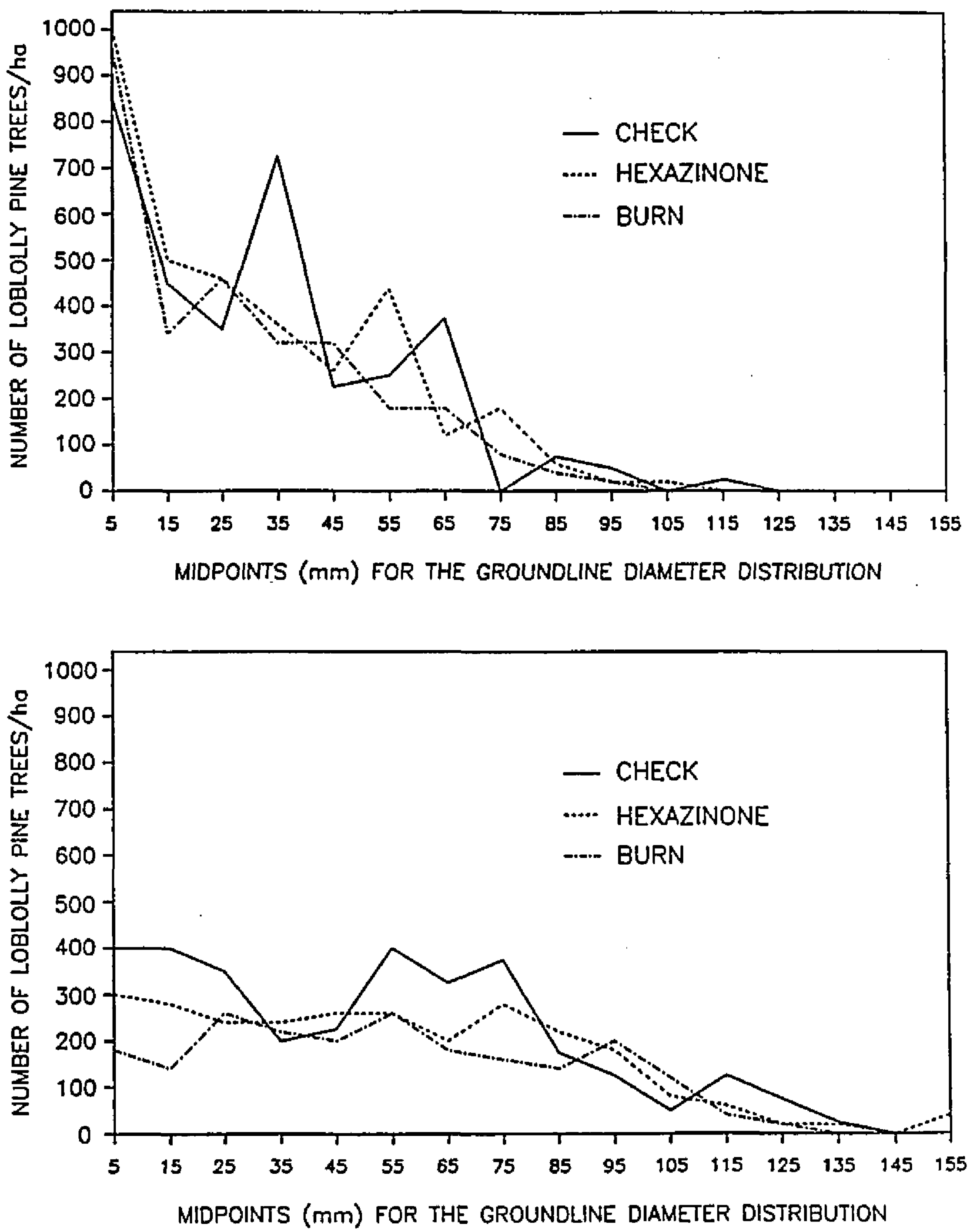

Figure 3. Groundline diameter distribution of loblolly pine trees before (top) and two growing seasons after treatments (bottom).

Before treatments, the height distribution of loblolly pine trees was concentrated in the smaller height classes (a reverse-J curve), and 29%, 32%, and 37% of the trees were either in the 0-0.49 m or 0.50-0.99 m class for the check, hexazinone, and burn treatments, respectively (Figure 4). Two growing seasons after treatments, the height distribution was more evenly distributed for all treatments, but 15%, 13%, and 11% of the trees remained in either the 0-0.49 m or 0.50-0.99 m class for the check, hexazinone, and burn treatments, respectively. Both before and after treatments, the height distributions were similar for all treatments.

Both before and after treatments, loblolly pine height, groundline diameter, inside-bark stemwood volume/tree, and volume/ha were not significantly different among treatments for the potential crop or suppressed pine trees (Tables 5, 6, 7, and 8). Within all treatments the mean height, groundline diameter, and volume/tree of the potential crop trees had increased significantly after treatment (Tables 5, 6, and 7). However, the mean stemwood volume/ha of crop trees increased significantly within the hexazinone (164%) and burn (175%) treatments but not within the check treatment (171%) (Table 8). I believe this indicates that the gains in yields were most uniform among potential crop trees within the hexazinone and burn plots, as suggested by the standard deviations. Thus, natural variation possibly contributed to these results because the actual changes in volume/ha were greater on the check plots (5.78 m^3/ha) than on the hexazinone (5.59 m^3/ha) and burn (4.31 m^3/ha) plots.

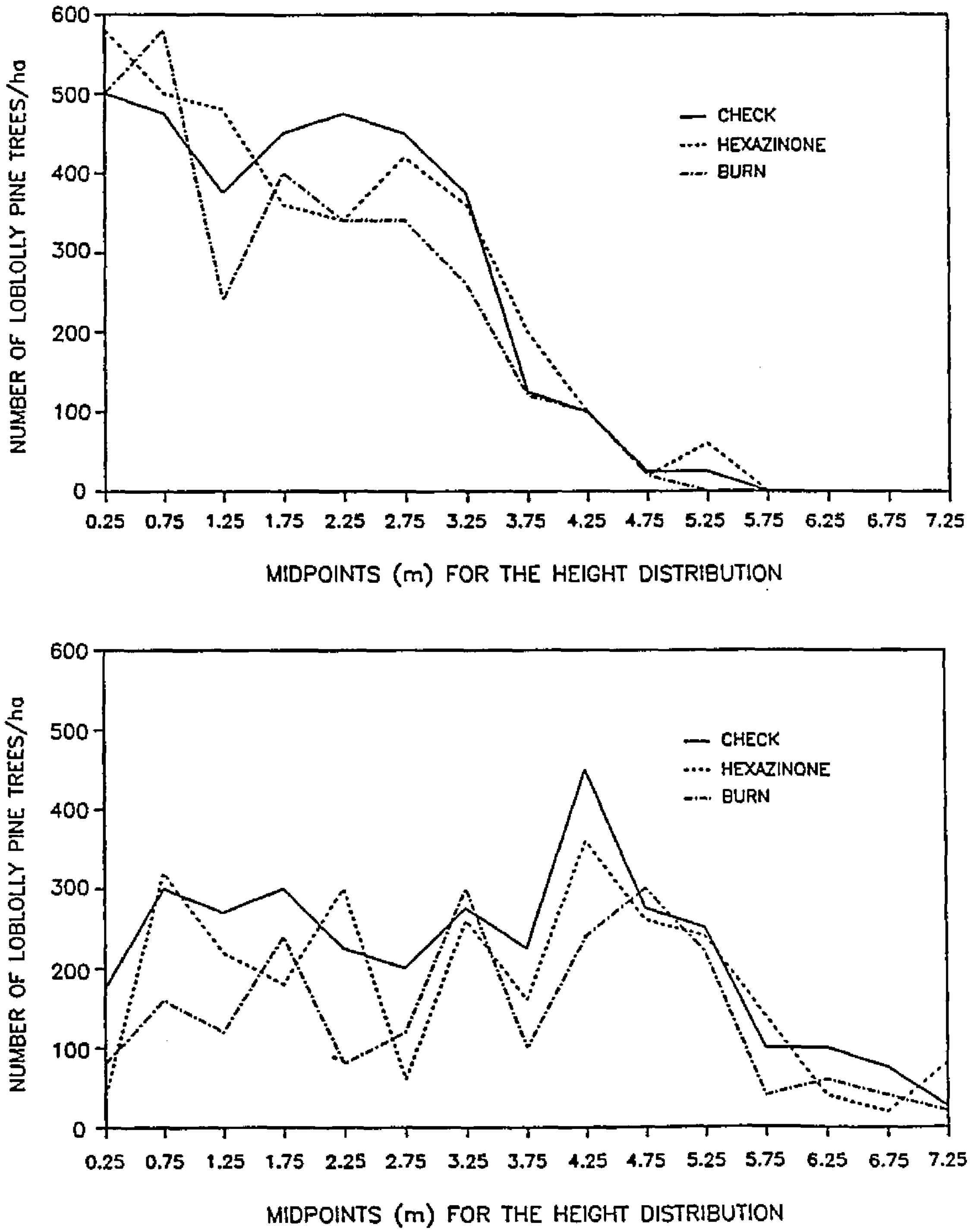

Figure 4. Height distribution of loblolly pine trees before (top) and two growing seasons after treatments (bottom).

Table 5. Average height of loblolly pine trees before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	----------(m)----------			
	Potential crop trees			
Before	2.53 (.15)[1/]	2.63 (.53)	2.49 (.36)	0.7866
After	4.51 (.41)	4.58 (.70)	4.61 (.59)	0.4132
Change	1.98 (.22)[2/]	1.95 (.39)	2.12 (.31)	0.6632
Prob. > t	0.0001 *	0.0010 *	0.0001 *	
	Suppressed trees			
Before	1.02 (.32)	1.05 (.41)	0.97 (.33)	0.9137
After	1.86 (.50)	1.83 (.17)	1.93 (.72)	0.8310
Change	0.84 (.30)	0.78 (.27)	0.96 (.35)	0.7696
Prob. > t	0.0292 *	0.0043 *	0.0261 *	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

* Within treatment, the before and after treatment heights are significantly different (P = 0.05), based on Student's t-test.

Table 6. Average groundline diameter of loblolly pine trees before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	----------(mm)----------			
	Potential crop trees			
Before	43 (3.42)[1/]	44 (7.54)	41 (3.56)	0.6227
After	75 (8.44)	75 (9.48)	76 (14.03)	0.4044
Change	31 (4.55)[2/]	31 (5.41)	35 (6.47)	0.5955
Prob. > t	0.0005 *	0.0004 *	0.0044 *	
	Suppressed trees			
Before	14 (5.53)	14 (4.64)	12 (4.98)	0.7511
After	25 (7.27)	25 (1.82)	27 (9.21)	0.6392
Change	11 (4.57)	12 (2.24)	15 (4.68)	0.4754
Prob. > t	0.0535 *	0.0008 *	0.0120 *	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

* Within treatment, the before and after treatment diameters are significantly different (P = 0.05), based on Student's t-test.

Table 7. Average inside-bark stemwood volume/loblolly pine tree at least 1.4 m tall before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	----- (dm^3) -----			
	Potential crop trees			
Before	2.0 (.57)[1/]	2.2 (.38)	1.9 (.21)	0.6232
After	5.7 (1.65)	6.2 (1.49)	6.1 (1.83)	0.3733
Change	3.7 (.87)[2/]	4.0 (.69)	4.2 (.82)	0.7343
Prob. > t	0.0057 *	0.0030 *	0.0069 *	
	Suppressed trees			
Before	1.2 (.10)	1.2 (.06)	1.2 (.03)	0.5365
After	1.8 (.84)	1.5 (.20)	1.5 (.25)	0.9200
Change	0.6 (.42)	0.3 (.10)	0.3 (.13)	0.7624
Prob. > t	0.2351	0.0194 *	0.0856	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

* Within treatment, the before and after treatment volumes are significantly different (P = 0.05), based on Student's t-test.

Table 8. Average inside-bark stemwood volume/ha of loblolly pine trees at least 1.4 m tall before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	---(m³/ha)---			
		Potential crop trees		
Before	3.38 (2.09)[1/]	3.40 (1.27)	2.46 (1.49)	0.2946
After	9.17 (5.77)	8.99 (3.37)	6.77 (3.26)	0.6288
Change	5.78 (3.07)[2/]	5.59 (1.61)	4.31 (1.60)	0.6281
Prob. > t	0.1085	0.0084 *	0.0273 *	
		Suppressed trees		
Before	0.65 (.38)	0.45 (.29)	0.52 (.06)	0.4307
After	1.88 (1.06)	1.11 (.30)	1.22 (.56)	0.3569
Change	1.24 (.56)	0.66 (.19)	0.70 (.28)	0.1467
Prob. > t	0.0709	0.0080 *	0.0879	

1/ Standard deviation among plots within treatment.

2/ Standard deviation appropriate to the difference between sample means within treatment.

* Within treatment, the before and after treatment volumes are significantly different (P = 0.05), based on Student's t-test.

Within all treatments, the height and diameter of suppressed pine trees increased significantly over the 2-year period (Tables 5 and 6). However, the mean stemwood volume/tree and volume/ha increased significantly within the hexazinone treatment (25% and 147%, respectively) but not within the check (50% and 197%, respectively) and burn (25% and 135%, respectively) plots. I believe this indicates that the gains in yields were most uniform on the hexazinone plots, as indicated by the standard deviations (Tables 7 and 8). Thus, natural variation contributed to these results because the actual changes in volumes were greater on the check plots (0.6 m^3/tree and 1.24 m^3/ha) than on the hexazinone (0.3 m^3/tree and 0.66 m^3/ha) and burn (0.3 m^3/tree and 0.70 m^3/ha) plots (Tables 7 and 8).

For hexazinone, I believe the within treatment results are partly related to the treatment process itself. The chance for hexazinone-related mortality depends mostly on two factors: (1) amount of herbicide absorbed by the pine tree and (2) the physiological condition of the pine tree (Minoque et al. 1988; Zutter et al. 1988a). Since hexazinone was uniformly applied, potentially it was equally available to all pine trees and this resulted in a more homogeneous effect on the pine trees than the erratic pattern of burning and intensity of the prescribed fire.

The small groundline diameter ($\bar{x}$ = 12 mm), height ($\bar{x}$ = 2.49 m), and thinner bark of the suppressed pine trees probably made them vulnerable to heat-related injury during backfiring (Chapman 1942, Greene and Shilling 1987, Lindenmuth and Byram 1948, McNab 1977, Waldrop and Lloyd 1988). Others have reported on the effects of fire on seedling pine trees. Greene and Shilling (1987) reported that a

fire intensity of 80 kJ/s/m killed 40% of the loblolly pine with groundline diameters of 30-40 mm. Cain (1983) found that a winter backfire of 59 kJ/s/m intensity killed all of the exposed loblolly pine trees under 1.4 m tall. With a winter backfire of 21-90 kJ/s/m, Waldrop and Lloyd (1987) found an inverse relationship between mortality of loblolly pine trees and diameter or height.

Hexazinone did not have had a positive effect on the growth and yield of potential crop trees when compared to the check trees. Perhaps more time is needed before differences among treatments become evident. In long-term work, Cain (1988) found that 24-year-old loblolly pine responded to control of competing trees after 23 years. Loblolly pine yields and hardwood tree basal area are inversely related (Langdon and Trousdell 1974, Zutter et al. 1988b), although results from individual pine-release treatments are often variable and inconsistent in operational comparisons (Glover and Dickens 1985).

The insignificant effect of fire on potential crop tree diameter and height is noteworthy, because fire is usually not applied in juvenile stands. Therefore prescribed fire can be used in juvenile pine stands provided the fire does not cause significant crown scorch. Potential crop trees in this mixed pine-hardwood stand had sufficient groundline diameter ($\bar{x}$ = 41 mm) to withstand a fire intensity even greater than that produced in this research. For example, Greene and Shilling (1978) found that loblolly pine trees with a groundline diameter of at least 50 mm were not usually killed by backfires at intensities as high as 98 kJ/s/m.

Competing Vegetation

Neither pine-release treatment influenced the total density (stems/ha) of hardwood trees significantly, although the number of stems decreased on the hexazinone plots and increased on the check and burn plots after two years (Table 9). The average height and diameter of all hardwood trees was significantly less on the hexazinone treatment than on the other two treatments (Tables 9, 19, and 21). The change in height and diameter over the 2-year period was significantly different between the hexazinone and check treatments (Tables 9, 20, and 22). Therefore, hexazinone reduced height and diameter of hardwood trees overall, but burning did not.

The changes in height and groundline diameter of sweetgum differed significantly between the check and hexazinone treatments (Tables 10, 23, and 24). During the study, the mean height of sweetgum increased 0.59 m on the check but decreased 0.18 m on the hexazinone treatment, and the change in mean diameter was +3 mm on the check vs. -4 mm on the hexazinone treatment. Sweetgum height and diameter results did not differ significantly between the hexazinone and burn treatments nor between the check and burn treatments. The number of sweetgum decreased 720 stems/ha on the hexazinone plots after two years, whereas the number of sweetgum increased 625 stems/ha on the check and 800 stems/ha on the burn plots. However, these treatment means were not significantly different.

Two years after treatments, oak density was significantly greater on the check (2,475 stems/ha) and burn (2,080 stems/ha) treatments than on the hexazinone treatment (900 stems/ha) (Tables 11 and 25). Changes in number of oak/ha was also significantly different among

Table 9. Density and size of all hardwood trees before and two growing seasons after treatments.

Measurement period	Treatments: Check	Treatments: Hexazinone	Treatments: Burn	Prob. > F
		Density (stems/ha)		
Before	8,550 (4,442)[1/]	7,600 (2,289)	7,440 (2,727)	0.5806
After	11,775 (7,587)	6,640 (3,601)	9,860 (3,535)	0.0960
Change	3,225 (4,396)[2/]	-960 (1,908)	2,420 (1,997)	0.0592
Prob. > t	0.4909	0.6285	0.2602	
		Average height (m)		
Before	1.73 (.33)	1.89 (.24)	2.01 (.34)	0.1894
After	2.26 A[3/] (.53)	1.98 B (.25)	2.47 A (.70)	0.0005
Change	.63 A (.31)	.09 B (.15)	.46 AB (.35)	0.0187
Prob. > t	0.0904	0.5635	0.2257	
		Average groundline diameter (mm)		
Before	23 (6.90)	24 (2.90)	25 (4.85)	0.5980
After	26 A (8.83)	21 B (3.21)	28 A (10.30)	0.0002
Change	3 A (5.60)	-3 B (1.93)	3 AB (5.09)	0.0344
Prob. > t	0.5551	0.1946	0.6792	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

3/ Within rows, treatment means followed by the same letter are not significantly different (P = 0.05), based on Duncan's Multiple Range Test.

Table 10. Sweetgum density and size before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	Density (stems/ha)			
Before	3,075 (3,542)[1/]	3,420 (1,657)	3,140 (2,462)	0.9792
After	4,700 (6,348)	2,700 (1,645)	3,940 (3,039)	0.1375
Change	+625 (3,635)[2/]	-720 (1,044)	+800 (1,749)	0.2030
Prob. > t	0.6705	0.5100	0.6596	
	Average height (m)			
Before	1.51 (.56)	1.82 (.24)	2.11 (.32)	0.0805
After	2.10 (.59)	1.63 (.35)	2.39 (.50)	0.0733
Change	+.59 A[3/] (.41)	-.18 B (.19)	+.28 AB (.26)	0.0416
Prob. > t	0.1958	0.3623	0.3190	
	Average groundline diameter (mm)			
Before	16 (7.52)	20 (2.67)	23 (4.31)	0.1998
After	19 (7.49)	16 (3.95)	22 (6.43)	0.0787
Change	+3 A (5.31)	-4 B (2.13)	-1 AB (3.46)	0.0380
Prob. > t	0.5944	0.1109	0.8810	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

3/ Within rows, treatment means followed by the same letter are not significantly different (P = 0.05), based on Duncan's Multiple Range Test.

Table 11. Oak density and size before and two growing seasons after treatments.

Measurement period	Treatments: Check		Treatments: Hexazinone		Treatments: Burn		Prob. > F
	Density (stems/ha)						
Before	2,300	(1,030)[1/]	1,580	(856)	1,720	(653)	0.4531
After	2,475 A[2/]	(1,170)	900 B	(775)	2,080 A	(753)	0.0019
Change	+175 A	(779)[3/]	-680 B	(516)	+360 A	(446)	0.0010
Prob. > t	0.8298		0.2242		0.4428		
	Average height (m)						
Before	1.59	(.72)	1.85	(.60)	1.73	(.54)	0.6654
After	2.49 A	(.94)	2.00 B	(.51)	2.37 AB	(1.12)	0.0008
Change	+.90 A	(.59)	+.15 B	(.35)	+.64 A	(.56)	0.0121
Prob. > t	0.1809		0.6838		0.2819		
	Average groundline diameter (mm)						
Before	24	(13.31)	28	(10.29)	26	(8.54)	0.6357
After	31 A	(14.64)	23 B	(8.84)	32 A	(14.98)	0.0089
Change	+7 A	(9.89)	-5 B	(6.07)	+6 A	(7.71)	0.0047
Prob. > t	0.5219		0.3834		0.4633		

1/ Standard deviation among plots within treatment.

2/ Within rows, treatment means followed by the same letter are not significantly different (P = 0.05), based on Duncan's Multiple Range Test.

3/ Standard deviation of the difference between sample means within treatment.

treatments: +175 on the check and +360 on the burn treatments vs. -680 on the hexazinone treatment (Tables 11 and 26).

Oak was significantly taller on the check (2.49 m) than on the hexazinone treatment (2.00 m), and mean height growth was greater on the check (+.90 m) and burn (+.64 m) treatments than on the hexazinone treatment (+.15 m) (Tables 11, 27, and 28). The mean diameter of oak was significantly greater on the check (31 mm) and burn (32 mm) treatments than on the hexazinone treatment (23 mm), and the change in mean diameter was also significantly different on the check (+7 mm) and burn (+6 mm) vs. hexazinone (-5 mm) treatments (Tables 11, 29, and 30). Oak density, height, and diameter did not differ statistically between the check and burn treatments. Therefore, hexazinone reduced density, height, and diameter of oak, but burning did not.

Within the check treatment, the number of red maple increased significantly by 1,050 stems/ha during the study, but red maple density did not increase significantly within the hexazinone and burn treatments (Table 12). Red maple height and diameter were not influenced by treatment.

The number of blackgum decreased 220 stems/ha on the hexazinone plots but increased 500 stems/ha on the check and 400 stems/ha on the burn plots (Table 13). However, these treatment effects were not significantly different. Blackgum height and diameter were not influenced by treatment.

Neither pine-release treatment influenced the density, diameter, and height of the other hardwood trees significantly when compared to the check (Table 14). The shrubs and blackberries were not significantly different among treatments either (Tables 15 and 16).

Table 12. Red maple density and size before and two growing seasons after treatments.

Measurement period	Check	Hexazinone	Burn	Prob. > F
	Density (stems/ha)			
Before	1,200 (258)[1/]	940 (680)	1,180 (1,078)	0.9017
After	2,250 (705)	1,620 (1,741)	1,960 (1,276)	0.8624
Change	+1,050 (375)[2/]	+680 (836)	+780 (747)	0.8635
Prob. > t	0.0312 *	0.4396	0.3269	
	Average height (m)			
Before	1.96 (.43)	1.99 (.54)	2.21 (.65)	0.6428
After	2.57 (.41)	2.69 (.93)	2.58 (.78)	0.4760
Change	+.61 (.30)	+.70 (.48)	+.37 (.45)	0.4582
Prob. > t	0.0865	0.1813	0.4364	
	Average groundline diameter (mm)			
Before	20 (6.97)	22 (6.75)	24 (9.14)	0.6186
After	22 (4.14)	27 (12.77)	24 (11.13)	0.5324
Change	+2 (4.05)	+5 (6.46)	0 (6.44)	0.6827
Prob. > t	0.6377	0.5410	0.9878	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

* Within treatment, the before and after treatment densities are significantly different (P = 0.05), based on Student's t-test.

Table 13. Blackgum density and size before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	Density (stems/ha)			
Before	1,350 (785)[1/]	1,110 (418)	900 (339)	0.3701
After	1,850 (1,300)	880 (487)	1,300 (787)	0.0995
Change	+500 (759)[2/]	-220 (287)	+400 (383)	0.1229
Prob. > t	0.5347	0.4654	0.3273	
	Average height (m)			
Before	2.18 (.53)	2.29 (.19)	2.29 (.63)	0.9615
After	2.66 (.37)	2.45 (.60)	2.76 (.98)	0.2455
Change	+.48 (.32)	+.16 (.28)	+.47 (.52)	0.5147
Prob. > t	0.1844	0.5922	0.3965	
	Average groundline diameter (mm)			
Before	31 (10.16)	32 (4.04)	34 (12.35)	0.9513
After	35 (9.26)	30 (9.81)	38 (16.67)	0.4031
Change	+4 (6.87)	-2 (4.74)	+4 (9.28)	0.4412
Prob. > t	0.5960	0.5825	0.6733	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

Table 14. Density and size of the other hardwood trees[1/] before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	Density (stems/ha)			
Before	625 (519)[2/]	560 (329)	500 (339)	0.9606
After	500 (337)	540 (365)	580 (438)	0.5088
Change	-125 (309)[3/]	-20 (220)	+80 (248)	0.5700
Prob. > t	0.7001	0.9297	0.7551	
	Average height (m)			
Before	1.17 (.21)	1.54 (.51)	1.52 (.41)	0.1849
After	1.92 (.70)	1.40 (.58)	1.97 (.43)	0.1970
Change	+.75 (.36)	-.14 (.35)	+.45 (.27)	0.1282
Prob. > t	0.0853	0.6983	0.1289	
	Average groundline diameter (mm)			
Before	17 (2.90)	18 (8.42)	18 (3.03)	0.9301
After	25 (9.32)	15 (7.47)	19 (4.11)	0.2156
Change	+8 (4.88)	-3 (5.03)	+1 (2.28)	0.3559
Prob. > t	0.1403	0.4896	0.4387	

1/ The other hardwood species were black cherry, winged elm, common persimmon, sassafras, fringetree, American holly, and southern magnolia.

2/ Standard deviation among plots within treatment.

3/ Standard deviation of the difference between sample means within treatment.

Table 15. Shrub density and size before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	Density (stems/ha)			
Before	18,075 (9,969)[1/]	22,040 (12,913)	21,380 (8,796)	0.9727
After	17,550 (5,692)	19,520 (7,583)	21,340 (5,695)	0.1644
Change	-525 (5,740)[2/]	-2,520 (6,697)	-40 (4,686)	0.1831
Prob. > t	0.9301	0.7165	0.9934	
	Average height (m)			
Before	0.67 (.13)	0.68 (.15)	0.65 (.17)	0.6435
After	0.78 (.08)	0.76 (.05)	0.70 (.12)	0.4959
Change	+.11 (.08)	+.09 (.07)	+.05 (.10)	0.5345
Prob. > t	0.2254	0.2532	0.6120	
	Average groundline diameter (mm)			
Before	6 (1.35)	7 (1.66)	6 (2.32)	0.6485
After	6 (.57)	6 (.81)	6 (1.60)	0.6857
Change	0 (.73)	-1 (.83)	0 (1.26)	0.4307
Prob. > t	0.9145	0.3527	0.7324	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

Table 16. Blackberry density and height before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	Density (stems/ha)			
Before	3,425 (2,037)[1/]	5,660 (2,522)	4,940 (2,642)	0.3637
After	1,600 (1,117)	3,240 (1,412)	2,920 (1,995)	0.3077
Change	-1,825 (1,161)[2/]	-2,420 (1,293)	-2,020 (1,481)	0.9301
Prob. > t	0.1672	0.0981	0.2096	
	Average height (m)			
Before	0.62 (.13)	0.70 (.11)	0.72 (.19)	0.4653
After	0.77 (.24)	1.05 (.38)	0.88 (.17)	0.6099
Change	+.15 (.14)	+.35 (.18)	+.16 (.11)	0.5660
Prob. > t	0.3270	0.1091	0.1883	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

and neither pine-release treatment influenced the surface coverage of herbaceous plants and vines (Table 17).

In my study, hexazinone reduced the density of oak and the heights and diameters of oak and sweetgum trees. Miller (1988) found soil spot applications of hexazinone effectively controlled sweetgum and water oak trees. However, burning did not significantly affect the potential hardwood competitors of loblolly pine. The first burn in a stand of trees often is limited in effect, and this was expected because safety of the potential crop trees from crown scorch and stem injury was of primary concern. Several burns within this juvenile mixed pine-hardwood stand may be needed before the brush is affected significantly.

Table 17. Average percentage of cover of herbaceous plants and vines before and two growing seasons after treatments.

Measurement period	Treatments: Check	Hexazinone	Burn	Prob. > F
	---------(percent)---------			
	Herbaceous plants			
Before	10 (4.3)[1/]	10 (5.4)	11 (5.3)	0.7332
After	7 (2.0)	7 (2.5)	11 (7.3)	0.4594
Change	-3 (2.4)[2/]	-3 (2.7)	0 (4.0)	0.3593
Prob. > t	0.1965	0.3581	0.9648	
	Vines			
Before	18 (10.6)	16 (5.2)	15 (2.9)	0.6963
After	15 (5.9)	19 (7.4)	15 (7.1)	0.1070
Change	-3 (6.1)	+3 (4.1)	0 (3.4)	0.0888
Prob. > t	0.6556	0.4049	0.9747	

1/ Standard deviation among plots within treatment.

2/ Standard deviation of the difference between sample means within treatment.

SUMMARY AND CONCLUSIONS

Interference by hardwood trees and shrubs reduces pine yields. Both prescribed burning and herbicides are used to control hardwood trees and shrubs on sites targeted for southern pine management. The sooner fire is used in juvenile stands the more efficiently the burn should control brush because of the smaller initial size of the competing vegetation, and subsequent burns should be more effective. In addition, fire is cheaper to use than mechanical or chemical methods of vegetation management.

On the other hand, herbicides can be applied in widely different plant communities of various sizes and under numerous weather conditions. Many types of herbicides and methods of application are available. This gives the silviculturist control and flexibility when choosing a treatment for a given site. Herbicides are known to be effective for brush control in juvenile pine stands, whereas very little is known about the usefulness of prescribed fire in these stands.

This field study was established on a Beauregard silt loam site in central Louisiana to compare prescribed burning and herbicide treatments for controlling potential competitors of juvenile loblolly pine trees within a mixed pine-hardwood stand seven years after clearcutting and mechanical site preparation. The prescribed method of burning was a low intensity backfire (87 kJ/s/m), which presumably

had a greater intensity near the ground and resulted in less crown scorch among the potential pine crop trees than a headfire would have. The selected herbicide was hexazinone, which is known to be effective on brush and is tolerated by pine trees.

The objectives of this study were:

1. to determine the 2-year effects of prescribed burning or hexazinone herbicide when used to control the potential competitors of juvenile loblolly pine trees, and
2. to compare prescribed burning and the herbicide treatments as methods of controlling the potential competitors of juvenile loblolly pine trees.

In this juvenile mixed loblolly pine-hardwood stand, the use of hexazinone herbicide and a winter backfire as pine-release treatments resulted in fewer suppressed pine trees/ha than the untreated condition. The reduction in number of trees may result in less intraspecific competition with the potential pine crop trees. However, suppressed trees are not normally major competitors. Within the hexazinone treatment, the number of potential crop trees decreased significantly, Neither vegetation management practice influenced loblolly pine diameter, height, and stemwood volume growth compared to the check over the 2-year period, but within both the hexazinone and burn treatments the volume/ha of potential crop trees increased significantly after two years. Therefore, treatments might have affected total stand growth. The insignificant effect of fire on juvenile loblolly pine diameter and height growth is noteworthy, because it shows that cool backfires can be used in relatively young

pine stands early in the rotation without severely injuring the majority of the trees.

The hexazinone treatment reduced the density of oak and the heights and diameters of oak and sweetgum trees. This reduction in competition may result in gains in diameter, height, and stemwood volume growth by the potential crop trees given more time for response. Based on Minoque et al.'s (1988) work, hexazinone broadcast over the foliage might have been more successful on this and other silt loam sites because hexazinone might exhibit poor lateral movement in silt loam soils and there might have been reduced root extension.

The winter backfire did not lead to a reduction in the brush after two years. However, the first burn in a stand of trees often is limited in effect, which was expected because safety of the potential crop trees from crown scorch and stem injury was of primary concern. Several burns within this juvenile mixed pine-hardwood stand may be needed before the brush is affected significantly, and the burning program should be continued.

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APPENDIX OF

STATISTICAL TABLES

Table 18. The analysis of covariance of plot means for the density (trees/ha) of suppressed loblolly pine trees two growing seasons after treatments.

ANCOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	1,082,225.710	8.65	0.0115
Treatment	2	1,158,704.174	18.52	0.0027
Density in 1985 as the covariate	1	132,704.174	4.25	0.0850
Error	6	187,735.874		
Corrected total	13	2,561,369.932		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	suppressed pine (trees/ha)	
Check	1,725	A
Hexazinone	1,260	B
Burn	1,000	B

Table 19. The analysis of covariance of plot means for the height (cm) of all hardwood trees two growing seasons after treatments.

ANCOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	4,133.57228	6.61	0.0218
Treatment	2	11,155.96881	35.70	0.0005
Height in 1985 as the covariate	1	11,206.21034	71.72	0.0001
Error	6	937.55740		
Corrected total	13	27,433.30883		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	height (cm) of all hardwood trees	
Check	235.929	A
Hexazinone	198.000	B
Burn	247.023	A

Table 20. The analysis of variance of plot means for the change in height (cm) of all hardwood trees over the 2-year study.

ANOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	4,561.99628	1.97	0.2043
Treatment	2	8,586.95945	7.40	0.0187
Error	6	4,059.50349		
Corrected total	13	17,208.45922		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
change in height (cm) of all hardwood trees		
Check	1,063.18[1/]	A
Hexazinone	1,009.23	B
Burn	1,045.84	AB

1/ Values are weighted by +1,000 to remove negative changes before analysis.

Table 21. The analysis of covariance of plot means for the groundline diameter (mm) of all hardwood trees two growing seasons after treatments.

ANCOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	111.705231	19.20	0.0014
Treatment	2	149.133074	51.28	0.0002
Groundline diameter in 1985 as the covariate	1	314.510115	216.28	0.0001
Error	6	8.725232		
Corrected total	13	584.073652		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	diameter (mm) of all hardwood trees	
Check	26.0206	A
Hexazinone	21.0321	B
Burn	27.5016	A

Table 22. The analysis of variance of plot means for the change in groundline diameter (mm) of all hardwood trees over the 2-year study.

ANOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	96.392228	2.05	0.1910
Treatment	2	133.089456	5.67	0.0344
Error	6	82.157541		
Corrected total	13	311.639225		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
change in diameter (mm) for all hardwood trees		
Check	103.501[1/]	A
Hexazinone	97.271	B
Burn	102.184	AB

1/ Values are weighted by +100 to remove negative changes before analysis.

Table 23. The analysis of variance of plot means for the change in height (cm) of sweetgum trees over the 2-year study.

ANOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	4,768.12553	0.77	0.5785
Treatment	2	16,080.71708	5.18	0.0416
Error	6	10,862.88110		
Corrected total	13	31,711.72371		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	change in sweetgum height (cm)	
Check	1,059.11[1/]	A
Hexazinone	981.67	B
Burn	1,028.02	AB

[1/] Values are weighted by +1,000 to remove negative changes before analysis.

Table 24. The analysis of variance of plot means for the change in groundline diameter (mm) of sweetgum trees over the 2-year study.

ANOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	59.9244324	1.29	0.3608
Treatment	2	125.9103981	5.41	0.0380
Error	6	81.5071899		
Corrected total	13	267.3420204		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	change in sweetgum diameter (mm)	
Check	102.982[1/]	A
Hexazinone	96.178	B
Burn	99.465	AB

1/ Values are weighted by +100 to remove negative changes before analysis.

Table 25. The analysis of covariance of plot means for the density (stems/ha) of oak trees two growing seasons after treatments.

ANCOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	824,542.9255	3.25	0.0963
Treatment	2	2,716,968.4915	21.39	0.0019
Density in 1985 as the covariate	1	5,576,343.5055	87.82	0.0001
Error	6	380,989.8279		
Corrected total	13	9,498,844.7504		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	oak density (stems/ha)	
Check	2,475	A
Hexazinone	900	B
Burn	2,080	A

Table 26. The analysis of variance of plot means for the change in density (stems/ha) of oak trees over the 2-year study.

ANOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	691,500.000	2.35	0.1533
Treatment	2	3,244,000.000	22.00	0.0010
Error	6	516,000.000		
Corrected total	13	4,451,500.000000		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	change in oak density (stems/ha)	
Check	10,175.0[1/]	A
Hexazinone	9,320.0	B
Burn	10,360.0	A

[1/] Values are weighted by +10,000 to remove negative changes before analysis.

Table 27. The analysis of covariance of plot means for the height (cm) of oak trees two growing seasons after treatments.

ANCOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	13,141.10928	4.09	0.0616
Treatment	2	18,389.86988	11.46	0.0089
Height in 1985 as the covariate	1	30,362.19751	37.83	0.0008
Error	6	4,815.17859		
Corrected total	13	66,708.35526		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	oak height (cm)	
Check	248.50	A
Hexazinone	199.93	B
Burn	236.94	AB

Table 28. The analysis of variance of plot means for the change in height (cm) of oak trees over the 2-year study.

ANOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	14,759.84548	3.92	0.0557
Treatment	2	16,628.10788	8.84	0.0121
Error	6	6,581.41625		
Corrected total	13	37,969.36961		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	change in oak height (cm)	
Check	1,089.91[1/]	A
Hexazinone	1,014.89	B
Burn	1,064.34	A

1/ Values are weighted by +1,000 to remove negative changes before analysis.

Table 29. The analysis of covariance of plot means for the groundline diameter (mm) of oak trees two growing seasons after treatments.

ANCOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	481.037585	5.02	0.0404
Treatment	2	549.420719	11.46	0.0089
Groundline diameter in 1985 as the covariate	1	655.726317	27.35	0.0020
Error	6	143.834490		
Corrected total	13	1,830.019111		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	oak diameter (mm)	
Check	30.837	A
Hexazinone	22.664	B
Burn	32.438	A

Table 30. The analysis of variance of plot means for the change in groundline diameter (mm) of oak trees over the 2-year study.

ANOVA

Source	Degrees of Freedom	Sum of Square	F Value	Prob. > F
Block	4	471.453641	5.38	0.0267
Treatment	2	556.748903	12.70	0.0047
Error	6	153.493133		
Corrected total	13	1,181.695677		

DUNCAN'S MULTIPLE RANGE TEST

Treatment	Mean	Grouping
	change in oak diameter (mm)	
Check	106.730[1/]	A
Hexazinone	94.404	B
Burn	105.940	A

1/ Values are weighted by +100 to remove negative changes before analysis.

VITA

James D. Haywood was born November 1, 1951, in Shreveport, Louisiana. After graduation from Jesuit High School in 1970, he entered Louisiana Tech University, Ruston. Later, in January 1972, he transferred to Louisiana State University, Baton Rouge, and graduated with a B.S.F. degree in Forest Management in May 1974. Upon graduation, he accepted a Forester position with International Paper Company, Brandon, Mississippi. In September 1975, he was admitted to the University of Maine at Orono under the Paul A. Gorman Fellowship awarded by International Paper Company. He graduated from the University of Maine at Orono in December 1977 with an M.S. degree in Forestry. The results of his research are recorded in the thesis: The Effects of 2,4,5-T, Amitrole, and Glyphosate Applied in the Springtime to Balsam Fir, Red Spruce, and White Spruce.

He returned to International Paper Company in December 1977, working in the Regional Technical Office, Natchez, Mississippi. Later he was transferred to the Natchez Area Office as the Landowner Assistance Forester.

Since September 1978, he has been employed as a Research Forester, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Alexandria Forestry Center, Pineville, Louisiana. His research assignments have involved silvicultural practices pertaining to site preparation before planting seedling pines, vegetation management with herbicides and fertilizers in

juvenile pine plantations, and growth and yield. Under these research topics, he has authored 25 publications and given 9 invited but unpublished presentations at technical conferences and workshops.

He holds membership in the Weed Science Society of America and the Soil and Water Conservation Society. From 1982 through 1987, he was either President, Vice President, or Secretary/Treasurer for the Central Louisiana Chapter of the Soil and Water Conservation Society, and from 1987 until the present, he has been the Secretary/Treasurer for the Louisiana Chapter of the Soil and Water Conservation Society. He received the Outstanding Service Award from the Louisiana Chapter of the Soil and Water Conservation Society in 1987. He is a member of Phi Kappa Phi and Xi Sigma Pi.

He was admitted to the Graduate School at Louisiana State University, Baton Rouge, in June 1982 and completed his residency and General Examinations in January 1985. He is now a candidate for the Ph.D. degree to be awarded in December 1988.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: James Davis Haywood

Major Field: Forestry

Title of Dissertation: Effects of Prescribed Burning or Hexazinone as Release Treatments in a Juvenile Mixed Loblolly Pine-Hardwood Stand

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination: